METALLURGIA

THE BRITISH JOURNAL OF METALS

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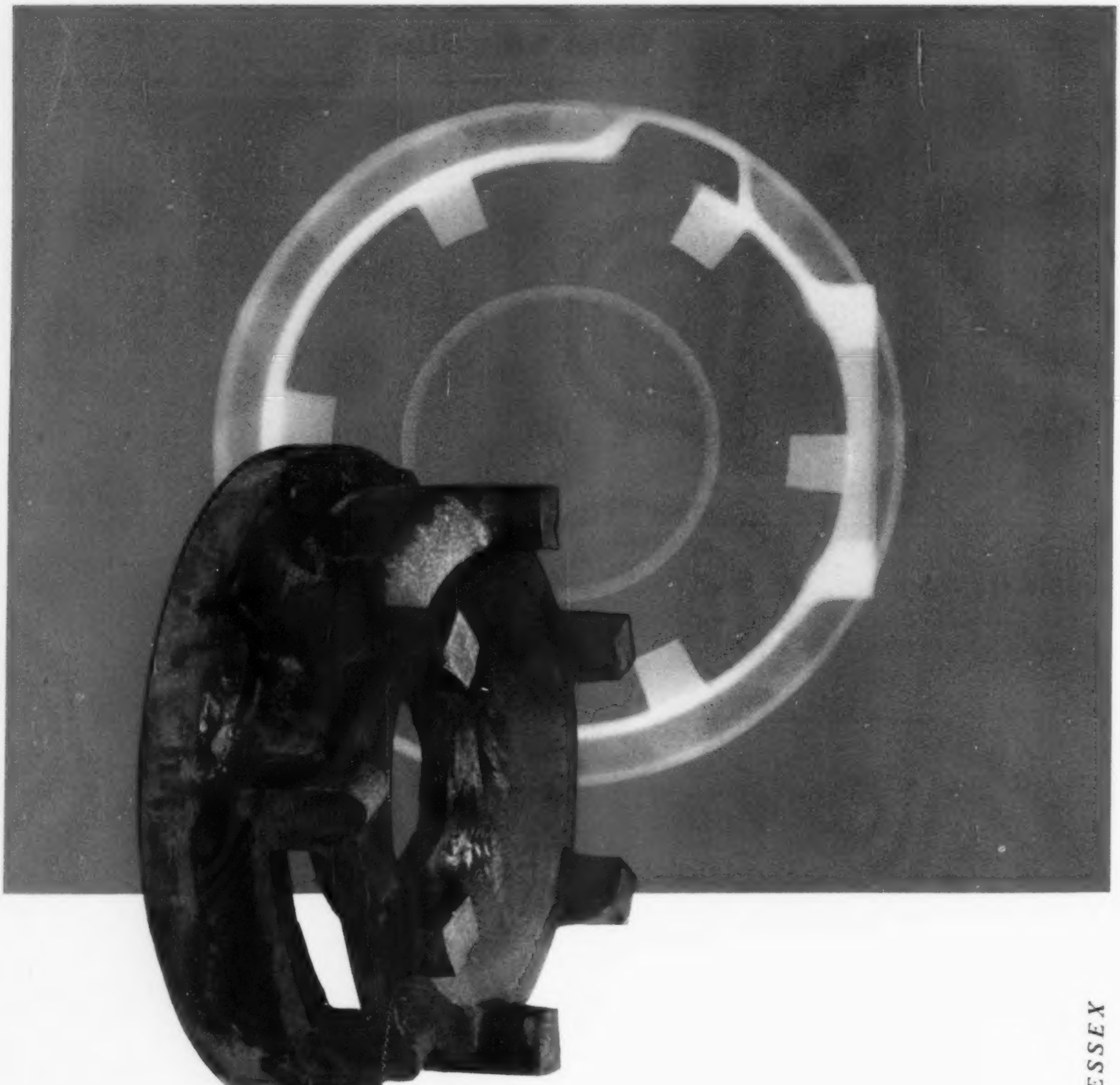

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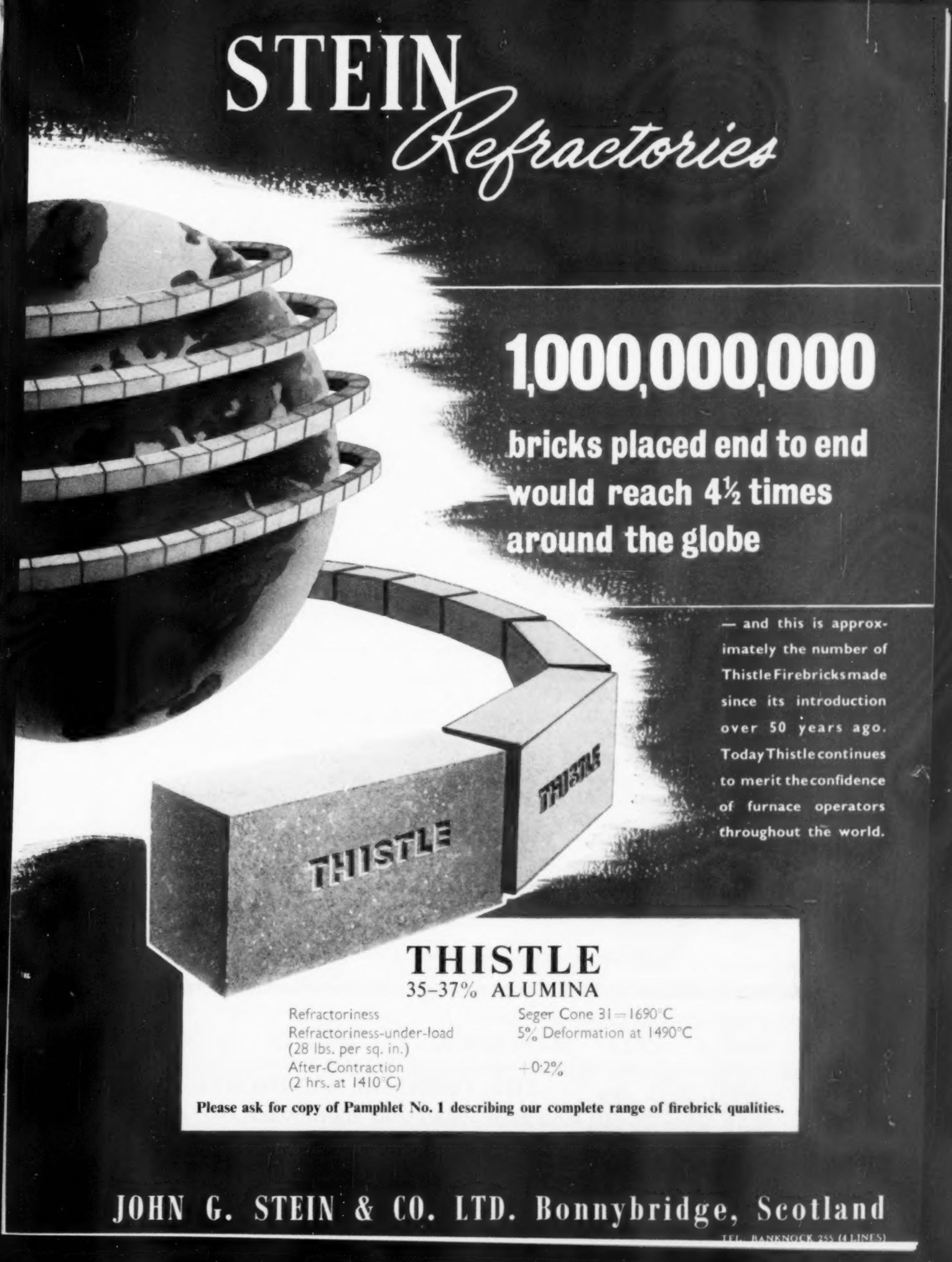
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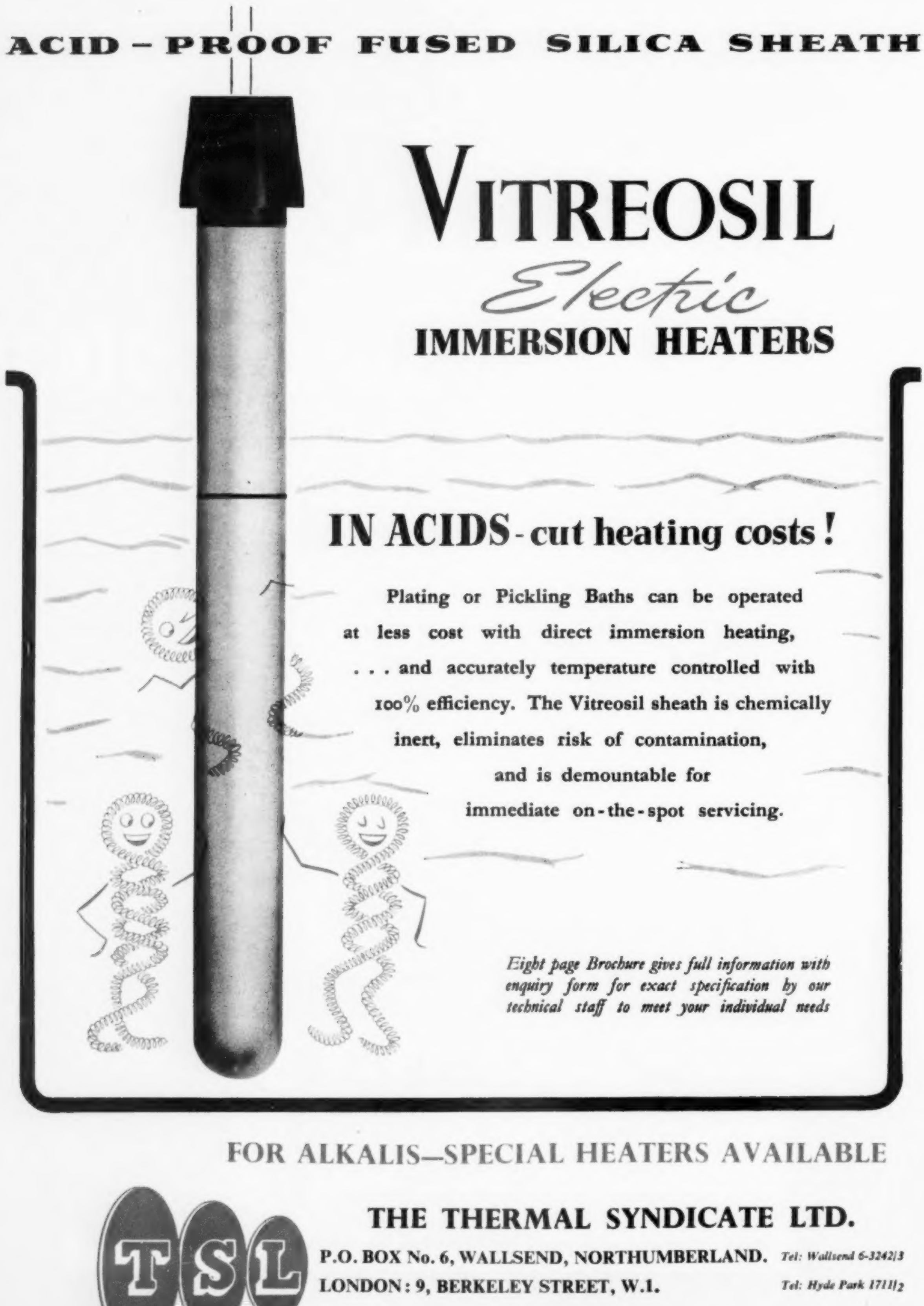
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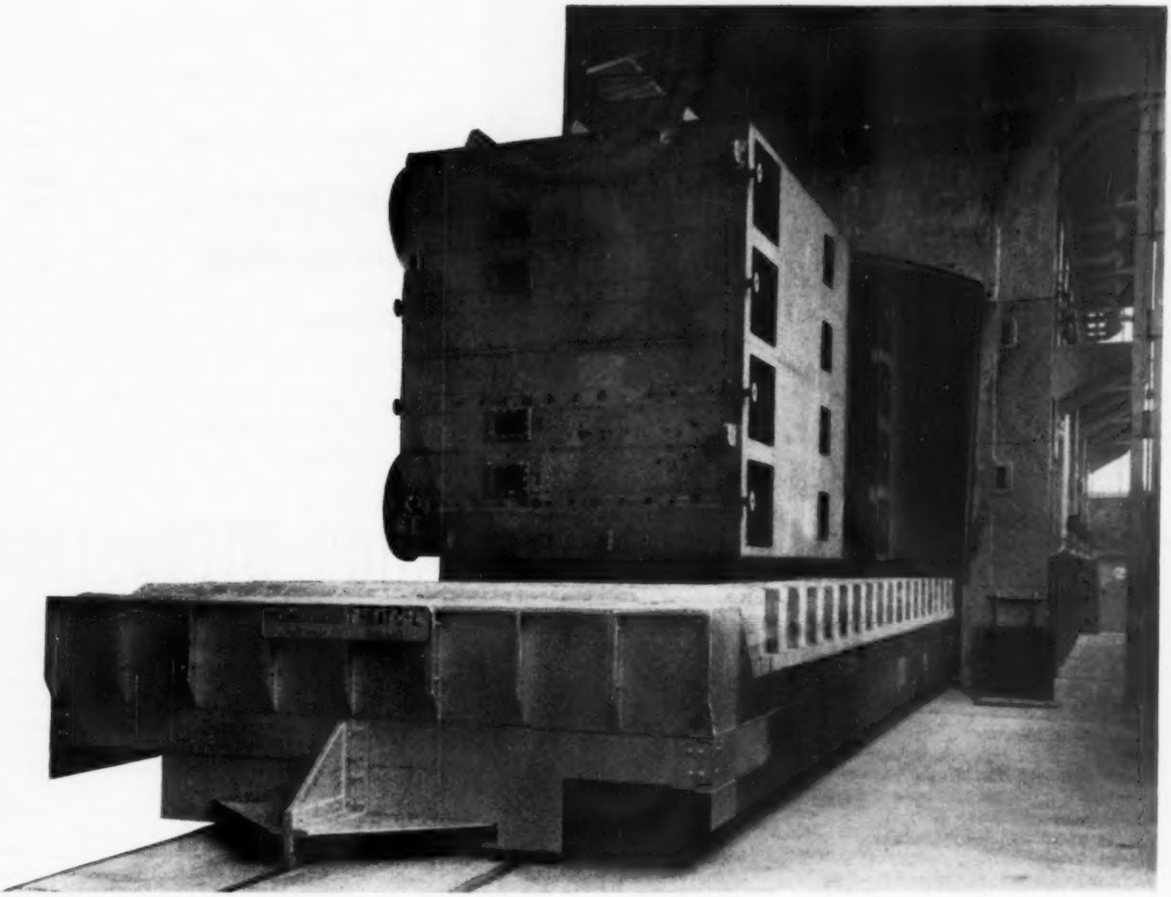
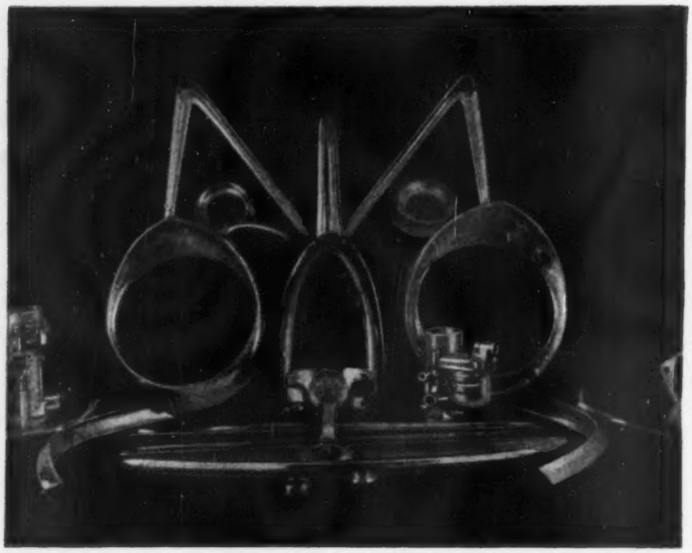




"We decided that Town Gas is the ideal fuel for the Diecasting Process"

Some diecast components made by T.A.L. Developments Ltd., Tottenham.

FUEL SELECTION FOR PRECISION DIECASTING

In August 1945 three men met together and their names were Thomas, Aldridge and Logan. They each put down enough money to create a small capital, and formed a Company which they called T.A.L. Developments Ltd.

Two of them, Aldridge and Logan, having been in diecasting all their lives, felt they knew enough about it to start on their own.

A small factory at Finsbury Park was rented and a labour force of 6 was recruited.

That was the humble origin of T.A.L. Developments Ltd.

Now the firm has a factory of 20,000 square feet, they employ about 120 workers and their capital is still the same. The Company has been built up by ploughing back the profits, until now the firm practically owns a modern factory complete with a modern diecasting plant, with a turnover that has increased nearly threefold in the last five years.

During conversation Messrs. Aldridge and Logan said that prior to 1939 diecasting had not reached the importance in this country that it has now, because large users other than the Motor Industry were the exception rather than the rule.

In 1939 and during the war years, both the Ministry of Aircraft Production and the Ministry of Supply were faced with the necessity of finding a substitute for machined components which were made from the solid bar, and they needed them in large quantities.

Diecasting was their answer. Tools were made for many thousands of intricate parts, and after the usual teething troubles were overcome, these pieces were produced by the hundreds of millions.

The Ministry very quickly realised that a very rigid control of the diecast material was necessary, and so stipulated that all zinc base alloys, used for their parts, were to a rigid British Standard Specification.

This ensured that the diecast parts retained their precise dimensional characteristics which was of vital importance when making delicate fuses, etc.

These facts are well known by T.A.L., who maintain their material to B.S.S., and to prevent any possible contamination use only one zinc alloy, namely, Mazak "3" with a regular analysis taken of material used on every day and night shift. All zinc alloy castings are therefore able to be produced to the British Standard quality, which is a sure sign of top quality.

Mr. Logan, who runs the production side of the factory, forbids the importation of even a small amount of solder into the factory, because of the danger of contaminating the zinc alloy with traces of lead or tin.

There is variety in plenty at the T.A.L. works. Among the larger zinc base pressure diecast components are the motor car headlamp bezels for a popular motor car. These are a complicated design and have to be chromium plated eventually and, to avoid rejects, it is essential that the surface quality of the diecastings is of a very high order. Motor car carburetter parts afford examples of a complex diecasting technique where the diecasting process has minimised machining and drilling costs to a considerable extent. At the other end of the scale there are diecast ladies' watch cases weighing only a few grams and cast so accurately that tiny pieces of marcasite can be fitted into the diecast settings.

Some of the diecasting machines have been bought complete but, what is of extreme interest are those machines which have been built by the firm themselves for their own use to meet special conditions of different contracts.

The diecasting process is well known. The zinc base alloy is melted in a furnace and the molten metal is pumped under high pressure into a steel die which forms the component to the shape of the die. Air valves open and close the die whilst operating the pump in a sequence so that the whole process takes place on a controlled temperature/time schedule. Such machines are built for relatively large, complicated diecastings. On the other hand, when it comes to long runs of relatively small diecastings, a nearer approach to automation is required.

The firm decided to build a number of completely automatic machines. They designed an electronic timer which, by operating the air valves, automatically opened the die, closed it, allowed molten metal to flow into it, then opened it and ejected the casting without any action by the operative, whilst a counting mechanism on the electronic timer told the operative precisely how many components had been turned out.

We turned on to the question of fuel, and on this Mr. Logan was quite emphatic. "Town gas appears to us to be the most suitable fuel for diecasting", he said. "We use gas because of the convenience factor first, then comes its reliability, and the Eastern Gas Board has always been ready to help us out of any troubles which do occur".

Mr. Aldridge added: "Yes, and of course it does mean that we have the simplest form of costing—the meter reading is there for us to see day by day and we can keep a close check upon the fuel cost per unit of output, and of course we know monthly or weekly fuel figures without having to attempt to determine how much solid fuel there is in a heap in the yard or how much liquid fuel there is in a tank".

Mr. Logan took it up from there and said: "You will notice that it is important that all the liquid metal in these diecast-

ing machines is maintained at a controlled temperature. A thermocouple in a protective sheath is located in the chamber containing the molten metal. This thermocouple sends a signal to the control pyrometer which is pre-set to the desired temperature. If the temperature exceeds the set point, then automatically the pyrometer sends an electrical signal to a solenoid valve which in turn operates the valve in the gas supply, so cutting down the gas and allowing the temperature to come back to its correct value. Town gas is therefore an ideal fuel for this process because it has a constant calorific value and is supplied at a governed pressure so that the temperature control is very easily maintained. In addition of course there are no fuel deliveries, no wasted storage space and it is the easiest fuel for the operatives to work with".

T.A.L. began by making zinc base alloy toys, for a large multiple store, and they made many millions of these before gradually changing their output and moving into motor car and general industries. It was interesting to learn that the increasing turnover of the company has not been due to any extensive publicity or to any form of high pressure salesmanship, it being accomplished as a result of doing a job at a reasonable price and producing consistent components so that one satisfied customer mentioned the name of the company to his friends in associated industries. That, with Mr. Aldridge's extensive technical knowledge, enabling him to give quick and accurate competitive costing is the true story of the growth of the company.

It is only when one visits a diecasting firm such as T.A.L. Developments that one realises the extent to which zinc base alloy diecastings fit into our pattern of life. There are gold plated zinc base diecastings for electric shavers. There are components for electrical radio and television sets made for leading firms in the electrical and radio industries—washing machine components—carburetter parts, etc.

Not only do the firm specialise in zinc base diecastings, but they also make considerable amounts of pressure aluminium alloy castings. The process here is somewhat different. The aluminium alloy is separately heated by gas in non-metallic crucibles, again on pyrometer control principle, and is ladled in the molten state into the diecasting machine. It is thus a cold chamber process as compared with making zinc base diecastings, which of course is a hot chamber process because the pressure cylinder is immersed in the molten metal.

Ever since 1945 the local Gas Board has collaborated with T.A.L. Developments —its Industrial Officers helped in the provision of piping when supplies were difficult, they made recommendations and acted as Consulting Engineers when the roof of the new factory had to be insulated to prevent heat wastage and the firm required a loan from the Ministry of Fuel and Power for this work to be done. The result of this co-operation is shown in the steady increase in the industrial gas sales load from the Eastern Gas Board to the company, which has doubled itself in the last five years.

"Some say town gas is an expensive fuel", was a remark put to him, and he smiled and said: "Well, I suppose any raw material used to make an end product is considered to be expensive by the manufacturer".

"But it is all a question of relative terms. We have a free choice to use any fuel we would wish and we have always used gas and see no reason why we are likely to change in the future. It is clean, it is provided at a constant calorific value. It is a flexible fuel which lends itself very easily to automatic temperature control so essential in our process, there is no storage space, there are no ashes to clear away and in short it is a piped fuel coming direct to us from the gas works. When we compared all these advantages and carefully worked out the relative fuel costs we decided that town gas was the ideal fuel for the diecasting process".

"Yes—it does mean that we have the simplest form of costing".

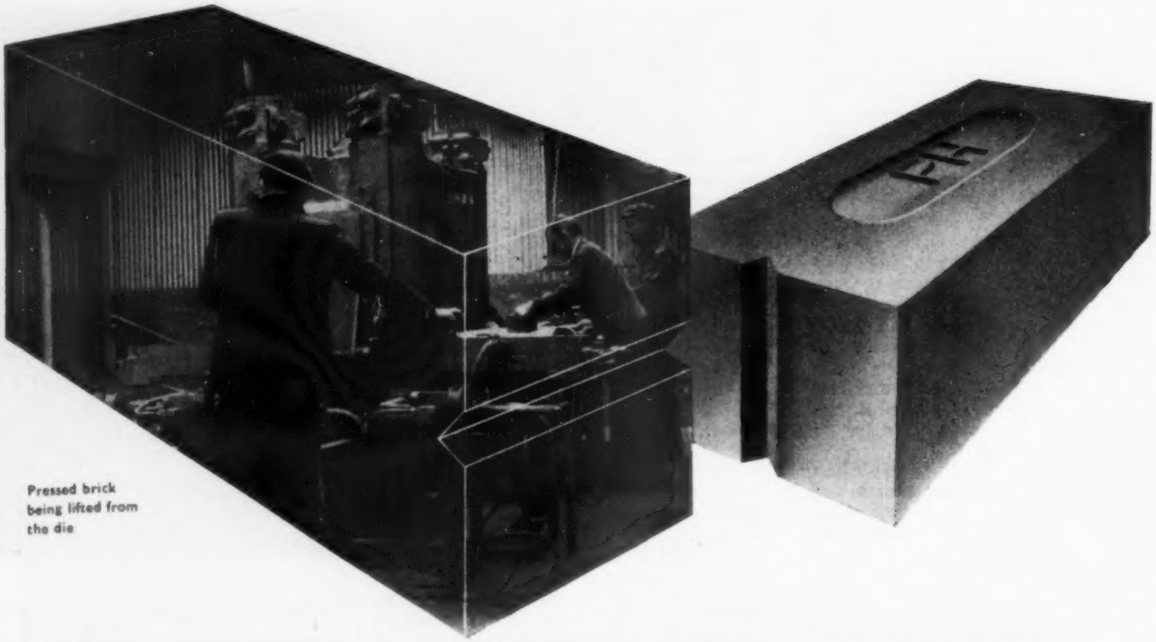
Each gas user has the advantage of the gas industry's pooled knowledge of so many different industries. An Industrial Gas Engineer of the Eastern Gas Board, for example, is always able to make use of the knowledge of the Industrial Officers in all the other area Gas Boards and has access to the Gas Technical Bureau in London, where a close watch is kept upon all progress in gas-fired equipment not only in the United Kingdom but also in overseas countries.

Precision diecasting is just one of the some 4,000 trades, professions and occupations benefiting from the constant research and development taking place in the Gas Industry.

Scottish Gas Board, Edinburgh.
Northern Gas Board, Newcastle-upon-Tyne.
North Western Gas Board, Manchester.
North Eastern Gas Board, Leeds.
East Midlands Gas Board, Leicester.
West Midlands Gas Board, Birmingham.
Wales Gas Board, Cardiff.
Eastern Gas Board, Watford.
North Thames Gas Board, London, W.8.
South Eastern Gas Board, Croydon.
Southern Gas Board, Southampton.
South Western Gas Board, Bath.

The Gas Council, 1 Grosvenor Place, London, S.W.1.

Typical diecasting machine open, showing the die. Molten metal heated by town gas is forced into the die.



Pressed brick being lifted from the die

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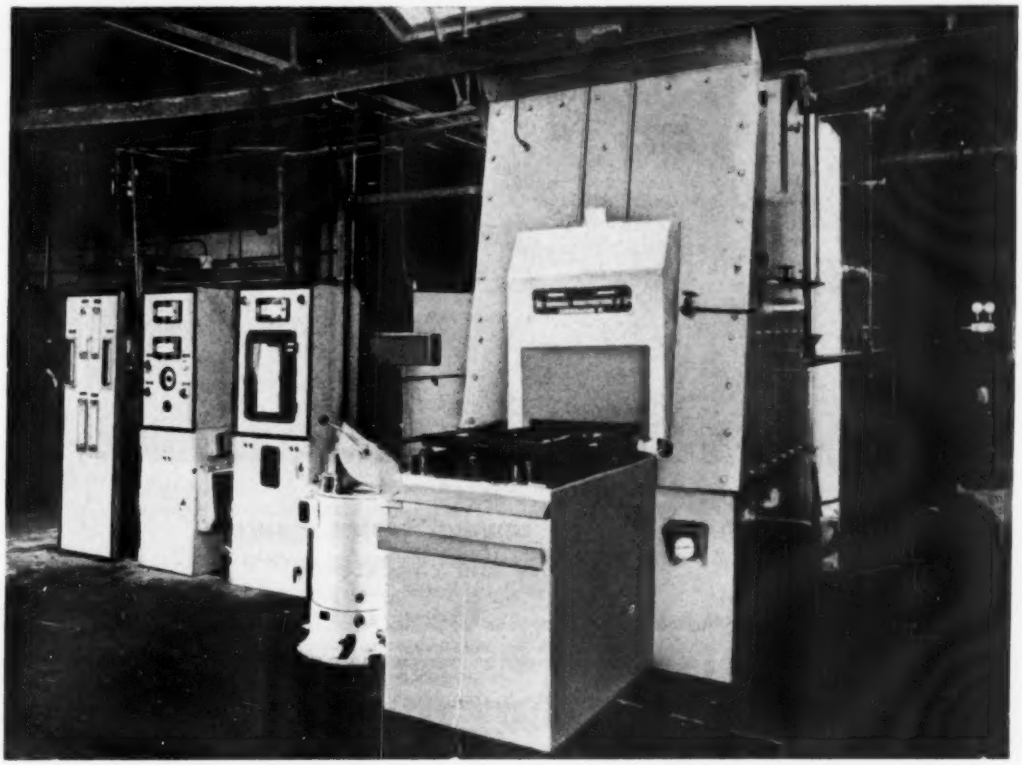

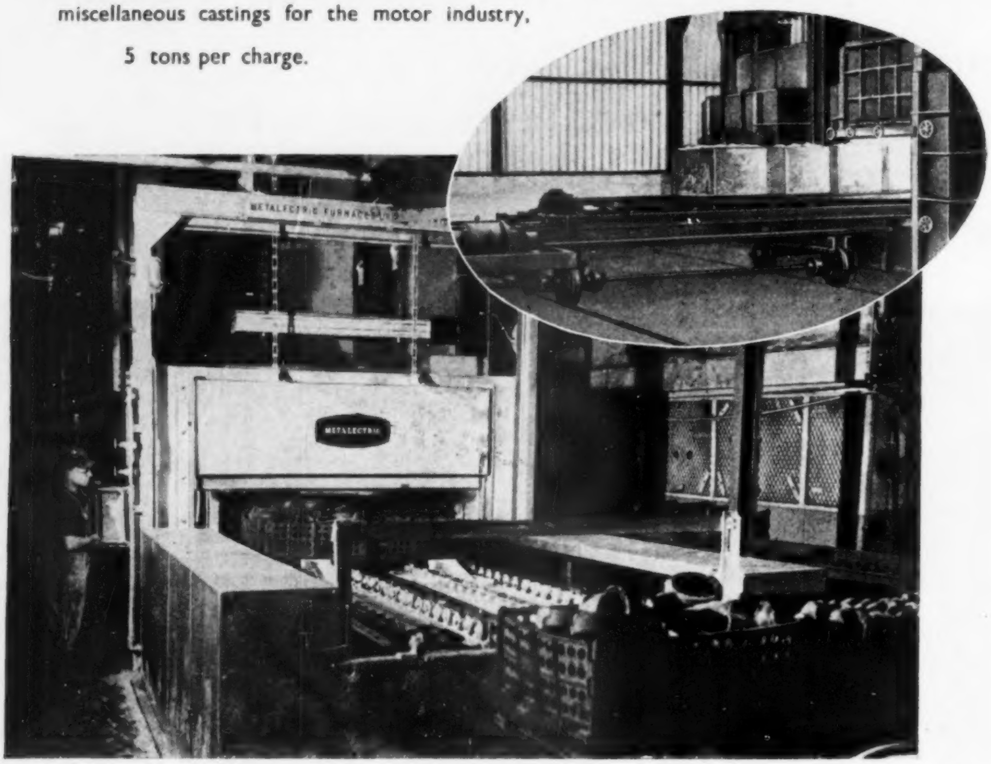

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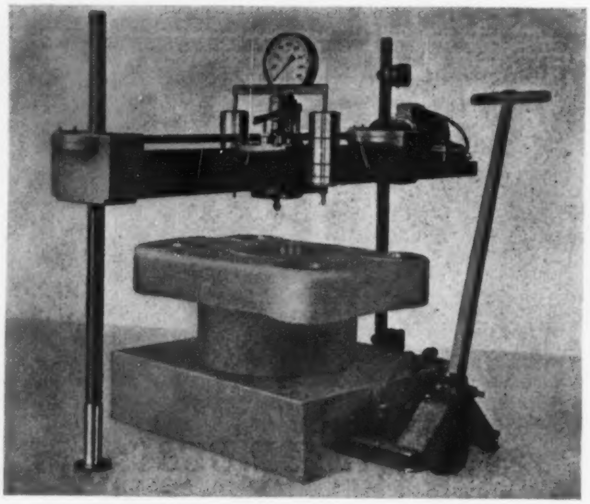

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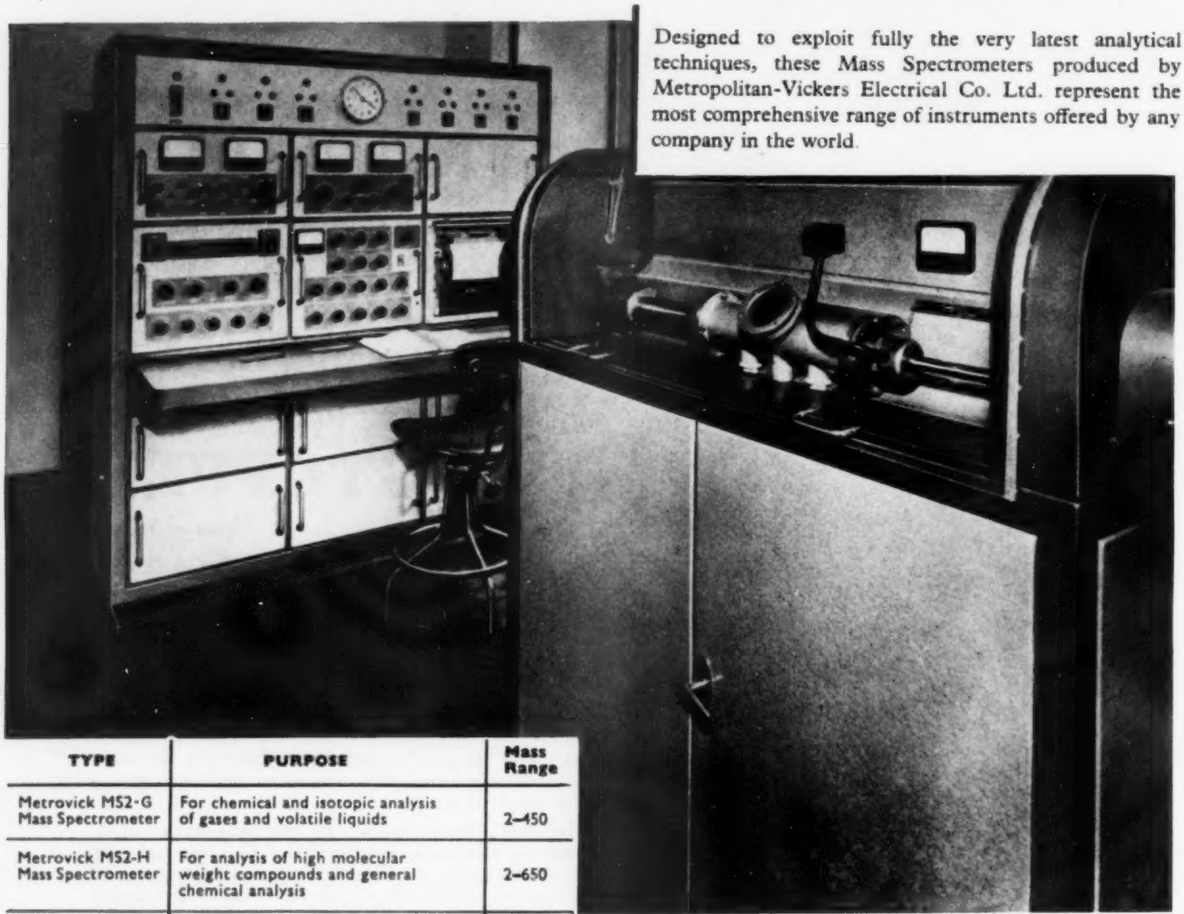

At Oxford University—A Metrovick MS5 Mass Spectrometer recently installed at the Department of Geology and Mineralogy.

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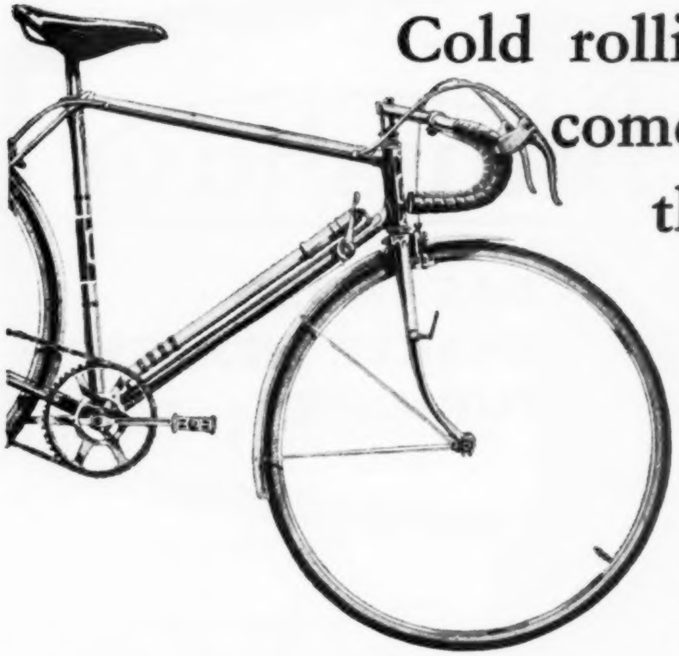

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General view of Brayshaw Shaker Hearth Furnace

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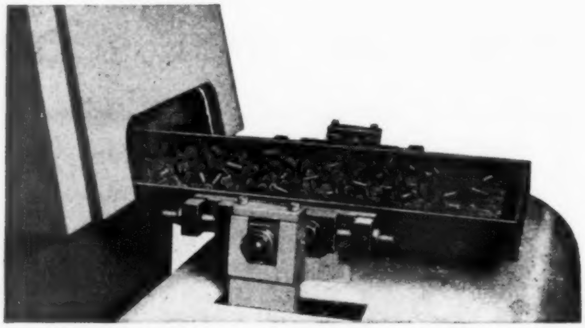

Close-up view of work tray with typical load of bolts

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SP 218

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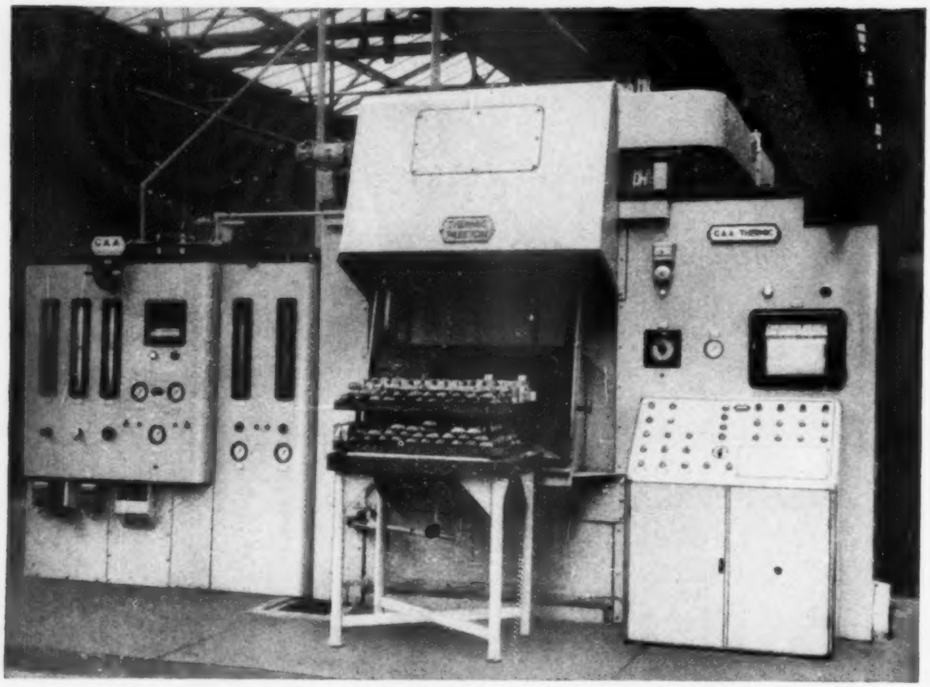
NEW STYLE HEAT TREATMENT



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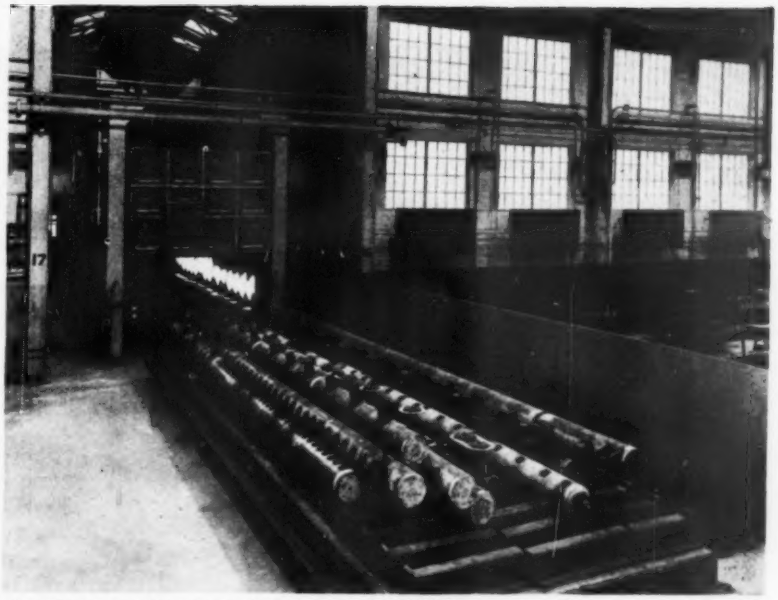
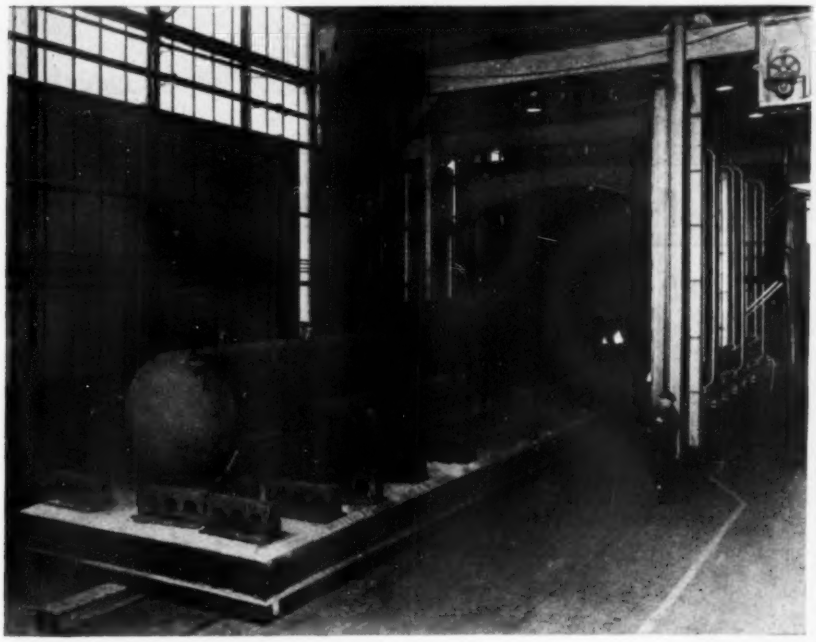


Heat Treatment Furnace in the Tube and Manifold Department of the Renfrew Works of BABCOCK & WILCOX LTD.

STRESS RELIEVING OF WELDED PRESSURE VESSELS



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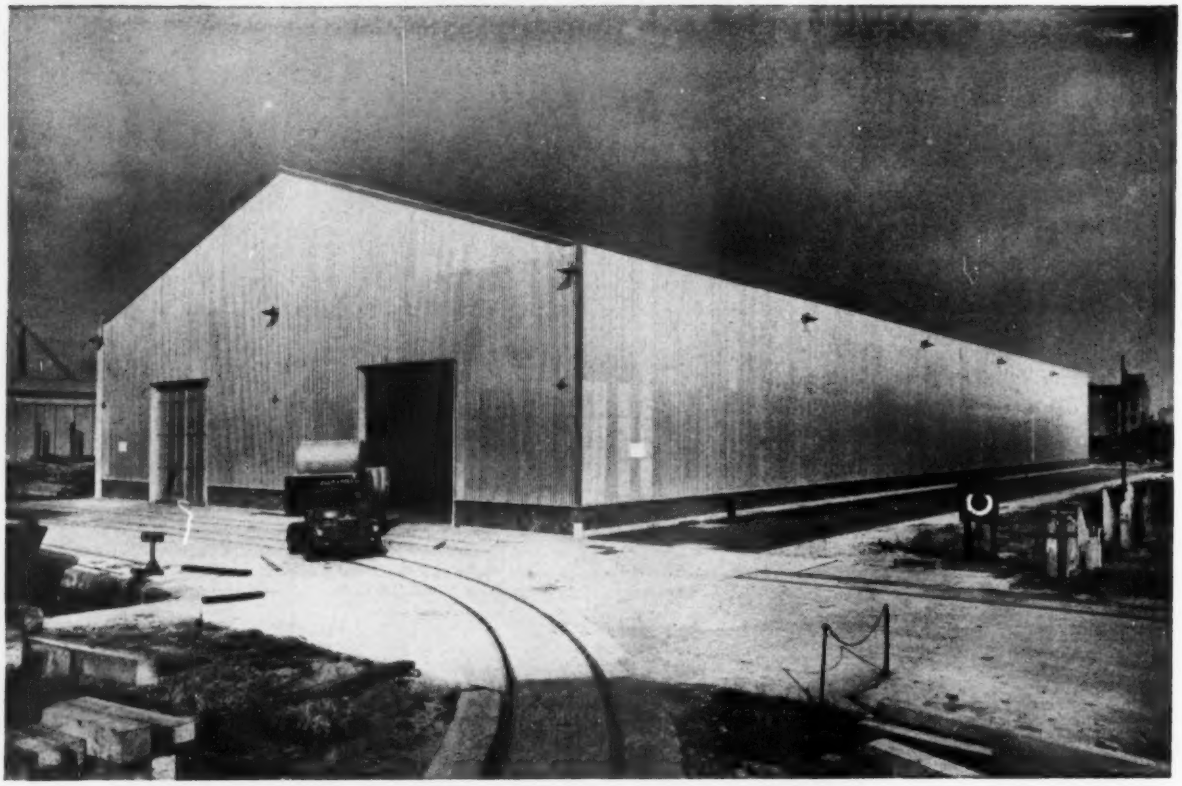

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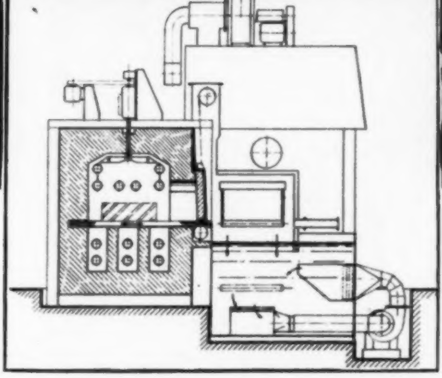

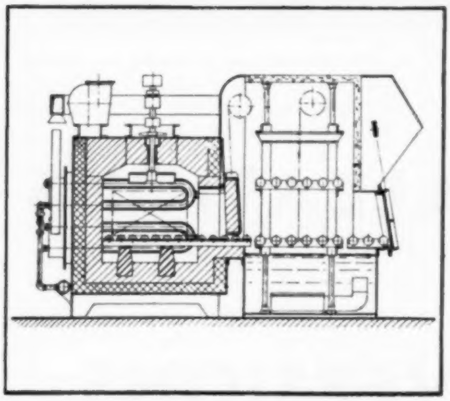

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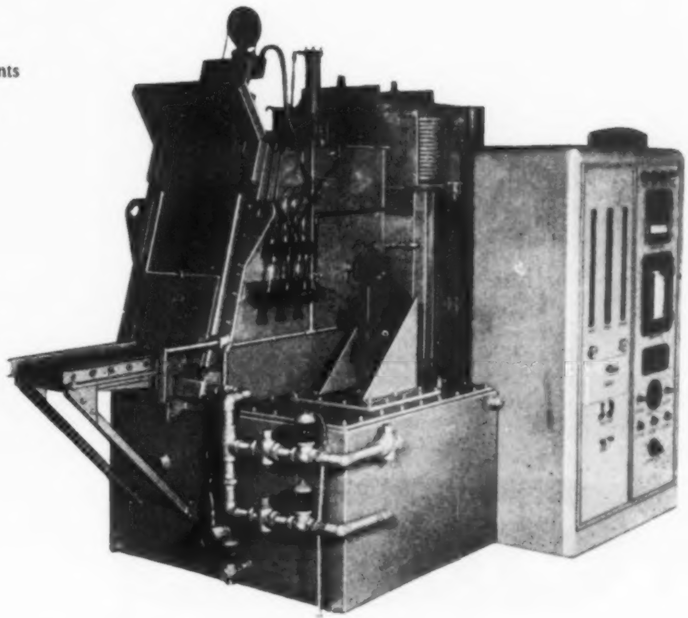

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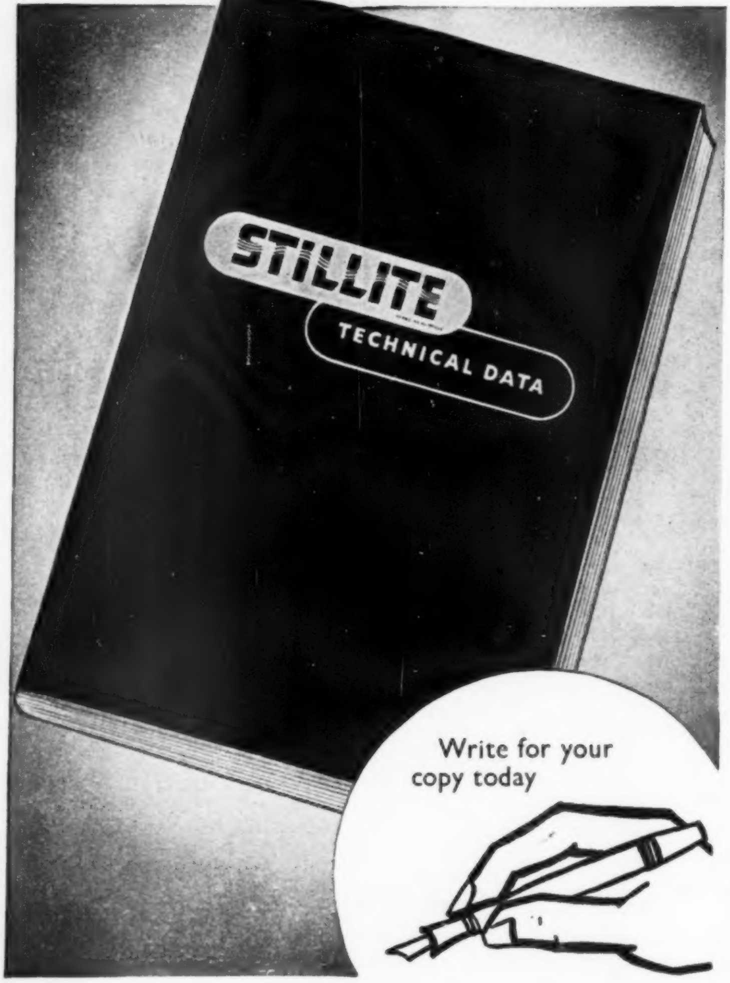

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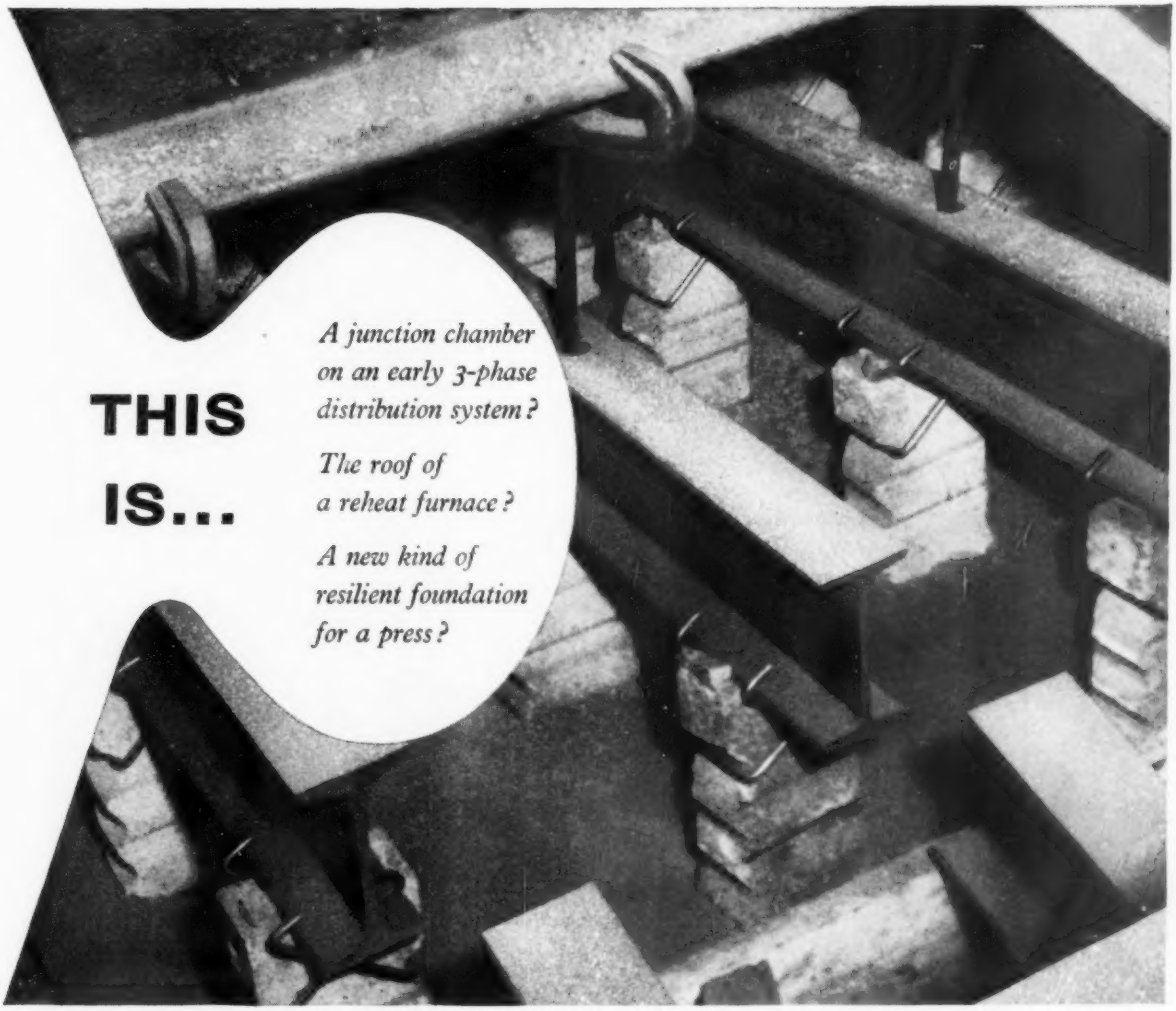

Number two is the right answer. It is part of the monolithic roof of a reheat furnace at the Margam works of the Steel Company of Wales, immediately before the refractory was placed.

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METALLURGIA

THE BRITISH JOURNAL OF METALS
INCORPORATING THE METALLURGICAL ENGINEER

CONTENTS FOR AUGUST, 1959 Vol. 60 No. 358

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METALLURGIA

THE BRITISH JOURNAL OF METALS

INCORPORATING THE "METALLURGICAL ENGINEER"

AUGUST, 1959 Vol. LX. No. 358

Support your Local Society

AS we come to the end of this truly remarkable summer, our thoughts turn to winter activities. To some, the change will be represented by a replacement of the leisurely tempo of cricket by the more energetic exercise involved in rugby or association football; to some, by more television; and to others, by a weekly session of hope with the football pool promoters; but to those engaged in science and technology it will also, one hopes, be associated with a renewal of the activities of the local technical societies.

Most provincial centres have a number of such societies, some of them of a purely local nature and entirely independent, others acting as local sections of, or being affiliated to, national institutions. In Manchester, for instance, more than forty societies—ranging in interest from industrial chemistry to engineering, from textiles to interplanetary travel (very much in the news at the moment), and from metallurgy to statistics—have for some years been associated in the Manchester Federation of Scientific Societies. The societies forming the Federation have a combined membership exceeding 11,000, and although there may be some duplication of membership, it should also be mentioned that the local groups of the senior engineering institutions have so far not seen their way to participate. Corresponding figures for other centres would no doubt indicate that the combined membership of local technical societies throughout the country is by no means inconsiderable.

The role of the local society is, perhaps, best considered in relation to the functions of the national institutions, which themselves vary in that some are professional bodies, membership of which calls for certain qualifications, whilst others are mainly concerned with publication of technical papers and the organising of meetings. In the metallurgical field, the professional body is, of course, the Institution of Metallurgists, which at the present time has no local sections, although in a recent discussion on a proposal that steps should be taken to amalgamate the Institution with the Iron and Steel Institute and the Institute of Metals, it was mentioned that young metallurgists already qualified by a university degree felt that they had little to gain by joining, and that the setting up of local sections was one way in which membership might be made more attractive. Such sections would, however, have rather limited scope if they were not to overlap the activities of existing local societies.

The Institute of Metals and the Iron and Steel Institute have achieved a world standing second to none as publishing bodies for metallurgical research, and the meetings arranged two or three times a year for the discussion of papers published by the Institutes are well attended by leading metallurgists and engineers. Such meetings provide an opportunity for criticism—both constructive and destructive—of an author's paper by fellow specialists in the field, and this, together with written contributions to the discussion, serves to help the reader to appreciate more satisfactorily the value of the paper. It follows, of course, that the attendance at such meetings is often confined to those having a particular interest in the subject, and it is possible to have an almost complete change of audience with a change in subject as a session of such a meeting proceeds. Exceptions to this are the meetings of the symposium type, where a number of related papers on a common subject are presented for discussion: the choice of subject is often one of wide interest and the attendance is usually considerably larger.

In considering the question of attendance at these technical sessions, it must be remembered that this may involve absence from the office, laboratory or works for two or three days in the case of members living far from the place of meeting, and this is not always expedient. There are, however, very real benefits to be obtained from an exchange of views on technical matters—whether made publicly or privately—such as is made possible by attendance at such meetings, and on these grounds alone there is much to be said for active participation.

It is here that the local societies come into their own, for they also provide an opportunity for "talking shop" with people in the same or a related field, and for hearing lectures on subjects of general interest to members, and of special interest to particular groups of members. Such lectures are not usually concerned with one particular piece of research work, but are rather in the nature of surveys of recent progress in particular fields, and as such are extremely useful. Neither extensive travelling nor absence from work is involved in attending the meetings of one's local society, but how many such societies find it necessary to hire halls capable of accommodating more than a third of their members? Even then there is a fair margin of safety.

The local society, as a publishing organisation, is limited in scope, owing to the high cost of printing, but as a forum it is of immense value. It seems a pity, therefore, that this value does not seem to be as widely appreciated as it might be. By their nature, local societies have to cater for a variety of members, and the attendance at meetings usually consists of a small hard core of regulars together with a changing group of members attracted by the particular subject under discussion. This savours of specialisation carried to excess, and it is difficult to imagine anyone who would not benefit from a broadening of his technical background. In any case, the same type of problem may be encountered in widely different fields, and the method used to deal with it may be capable of widespread adoption, so that from a practical point of view there is much to be said for more effective support of local technical societies. Will you be going more often this winter?

Personal News

MR. R. C. ORGILL, O.B.E. has been appointed Agent for the Davy-United Sections of the contract for building a steelworks at Durgapur, India, which is being carried out by Indian Steelworks Construction Co., Ltd., a consortium of thirteen British firms.

MR. C.A.B. MALDEN has been appointed Joint Managing Director, with MR. J. G. CRONK, of Amber Oils, Ltd. He joined the Company in 1958 from Stephenson Clarke, Ltd.

MR. E. SEYMOUR-SEMPER, has been elected President of the Institute of Welding for 1959–60. The two new Vice-Presidents elected this year are MR. W. BARR, O.B.E., and MR. E. FUCHS.

MR. J. BUSFIELD, recently appointed Secretary and Chief Accountant for Crofts Engineers (Holdings), Ltd., and Crofts (Engineers), Ltd., has been appointed a Director of both Companies, and of J. Parkinson and Son (Shipley), Ltd. MR. M. T. J. GOFF, Joint Managing Director of Crofts (Engineers), Ltd., since 1951, and a Director of Crofts Engineers (Holdings), Ltd., since 1954, has also been appointed a Director of J. Parkinson and Son (Shipley), Ltd.

THE ROYAL SOCIETY has been informed that DR. L. ESSEN, a Senior Principal Scientific Officer at the National Physical Laboratory, has been awarded the A. S. Popov's Gold Medal by the Academy of Sciences of the U.S.S.R. This award is for the most distinguished scientific work in the field of radio-engineering performed during the period from 1956 to 1958. The work of scientists from all countries is considered, but this is the first time that it has been awarded to a scientist outside the Soviet Union. The importance of Dr. Essen's work on time standards was recently recognised by the presentation of the first Wolfe Award, given to the research worker considered by the Department of Scientific and Industrial Research to have made an outstanding contribution to the research work of the Department during 1958.

THE appointment is announced of PROFESSOR J. S. ANDERSON, F.R.S., as Director of the National Chemical Laboratory, D.S.I.R. Dr. Anderson, who is Professor of Inorganic and Physical Chemistry at the University of Melbourne, succeeds the retiring Director, DR. D. D. PRATT, C.B.E., and is expected to take up his new duties in October.

MR. A. A. SMITH, Head of the Welding Processes Section of the British Welding Research Association, has been temporarily seconded by the Association to the Department of Scientific and Industrial Research for attachment to the staff of the United Kingdom Scientific Mission in Washington, U.S.A. Mr. Smith, who is an expert on the modern gas-shielded welding processes, is to pay special attention to American developments in this field and any related ones of automatic welding: his tour of duty in America will be about five months.

VICKERS, LTD., announce that SIR LESLIE ROWAN, K.C.B., C.V.O., who joined the Board in December 1958, has now been appointed Director of Finance of Vickers, Ltd. Sir Leslie has also been appointed a Director of Vickers-Armstrongs, Ltd., and Robert Boby, Ltd.

THE INDIAN STEELWORKS CONSTRUCTION CO., LTD., announce with regret the resignation of BRIGADIER M. H. COX from the post of Resident Director at Durgapur as from August 10th, 1959. He is succeeded by MR. D. J. BELL, who was with Stewarts and Lloyds, Ltd., before being appointed to ISCON as General Manager, Durgapur Steel Project.

THE RT. HON. THE LORD ROCHDALE, O.B.E., T.D., D.L., has accepted a seat on the Board of Geigy (Holdings), Ltd., of Manchester.

MR. L. R. P. PUGH, Director and Secretary of Guest Keen Iron and Steel Co., Ltd., has been appointed Assistant Managing Director, and is succeeded as Secretary by Mr. C. F. PAGNAMENTA, O.B.E., at present Chief Accountant. MR. B. W. JOHN, at present Assistant Secretary, succeeds Mr. Pagnamenta as Chief Accountant.

BRITISH INSULATED CALLENDER'S CABLES, LTD., announce the retirement of MR. W. G. HENDREY, who has been a Director since 1938. MR. W. FRASER, Chairman and Managing Director of Scottish Cables, Ltd., has been appointed to the B.I.C.C. Board.

THE VISCOUNT KNOLLYS, G.C.M.G., M.B.E., D.F.C., the Chairmen of Vickers, Ltd., has been elected Chairman of English Steel Corporation, Ltd., in succession to the late Sir Frederick Pickworth.

THREE new appointments have been made in The English Electric Company's export organization following that of Mr. L. A. Short as Director of Overseas Operations and recent expansion of the Division's activities. MR. J. F. HERBERT has been appointed General Manager Export Sales, in which post he will continue to have special responsibilities for the overseas interest of the Company's Atomic Power Division ; MR. S. E. BOLTON has been appointed Assistant General Manager Export Sales, with special interests in the North American Continent, for which territory he has been Area Export Manager since 1955 ; and MR. S. W. J. BUTLER, who has been in charge of the Company's Overseas Factories Services since 1951, has been made Manager of a new Overseas Factories Department. This department has been established in view of the increasing importance of manufacturing in overseas territories.

MR. H. J. TUCKER, Southern Area Sales Manager for the Electric Resistance Furnace Co., Ltd., for the past ten years, has been appointed Service Manager, with responsibility for maintaining customers' goodwill. He will be able to call on the full resources of the company to ensure that users of Efco furnaces obtain complete satisfaction from their installations. MR. C. A. MCNEILL formerly technical sales manager of another furnace manufacturing company, has joined the technical sales staff at the Midland Area Office in Birmingham. MR. M. J. PARSONS, who has worked for many years with Edwards High Vacuum, Ltd., has joined the E.R.F.C.O. sales organisation at the Head Office, Weybridge : he will specialise in vacuum heat treatment processes and equipment.

IN a reorganisation of the Sales Division of Nash and Thompson, Ltd., MR. J. L. FOREMAN, formerly Commercial Manager of the Elliott-Automation Group, has been appointed Sales Manager, with responsibility for sales policy, publicity and market research. MR. D. E. MORRIS has been promoted to Sales Office Manager, with special responsibility for process control, oil, gas, mining, medical and survey equipment. MR. R. C. BLEZARD is the Sales Engineer responsible for all metallurgical sales, and MR. T. N. MORDUE covers the counties south of the Thames for the Nashton range of miniature electronic test equipment. The sale of scintillators is now covered by MR. D. A. GINGER, the Chief Chemist, and environmental testing by MR. G. F. THOMPSON, Head of the Component Testing Laboratory.

MR. E. BENTLEY, for the past two years Manager of the Manchester Branch of Griffin & George (Sales), Ltd., has been appointed London Branch Manager. He is succeeded at Manchester by MR. K. FREER, with MR. J. BRANSON, formerly Yorkshire representative, as Assistant Manager. MR. D. SAVAGE remains Field Sales Manager (Northern Area).

MR. A. B. JORDAN has been appointed Publicity Manager of Edgar Allen & Co., Ltd., in succession to MR. E. N. SIMONS. MR. SIMONS will be retained as a Publicity Consultant and as Editor of *Edgar Allen News*, a position he has occupied since its inception forty years ago.

MR. W. E. A. REDFEARN, Director, English Steel Corporation, Ltd., Deputy Managing Director, English Steel Forge & Engineering Corporation, Ltd., and Director, English Steel Rolling Mills Corporation, Ltd., has been appointed Chairman of the National Forgemasters' Association in succession to the late Sir Frederick Pickworth.

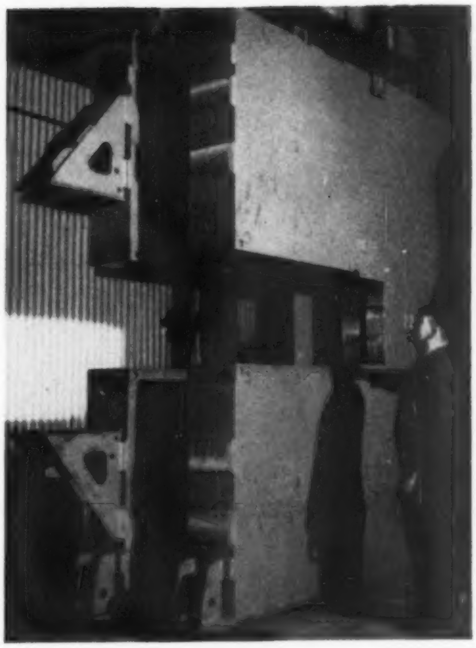
AT a recent meeting of the Board of Aluminium Laboratories, Ltd., in Montreal, DR. R. T. PARKER was elected a Director and Vice-President of the Company. Dr. Parker recently took charge of the Banbury and Geneva offices of the company in succession to Mr. R. D. Hamer. At the same meeting DR. D. E. THOMAS, Head of the Department of Patents and Contracts, was appointed an Assistant Secretary.

DAVY AND UNITED ROLL FOUNDRY, LTD., Billingham, Co. Durham, announce the appointment as Works Manager of the Roll Foundry of MR. A. C. BIRD, who was previously Assistant Works Manager.

MR. G. B. PERRY has been appointed Managing Director of Axia Fans, Ltd., a member of the Hall-Thermotank Group of Companies. He has also been appointed a Director of Vent-Axia Ltd., and will retain his seat on the Board of Thermotank, Ltd., in which Company he formerly held the executive posts of Director, Engineering Division, and General Manager of its International Products Division. As a result of Mr. Perry's appointment, MR. R. C. ADIE has been promoted to be General Manager of Thermotank's International Products Division, and MR. H. J. WATSON will be General Manager of the Engineering Division.

Production of Magnet Sectors for 7 GeV Proton Synchrotron

Accuracy Required Necessitated Development of Special Manufacturing Techniques



Two of the 20-ton magnet sectors: that on the left has the coil brackets welded in place.

A 7,000 ton electromagnet core—the biggest in the British Commonwealth and the heaviest in Europe outside the U.S.S.R.—is now being constructed at Manor Works, one of the Wolverhampton factories of Joseph Sankey and Sons, Ltd. When completed, the magnet will form the largest component of the £7 million 7 GeV proton synchrotron—a 7,000 million electron volt "atom smasher"—being built at the Rutherford High Energy Laboratory, Harwell, for the National Institute for Nuclear Research. The synchrotron, which is due for completion in 1961, will be Britain's most powerful tool for fundamental research in nuclear physics, and is intended to provide universities and other institutions with facilities and equipment which are beyond their reach, both financially and physically.

The completed magnet ring will be 160 ft. in diameter, but, because of transportation and installation problems, it is being produced in 336 radial sectors, of which two may be seen in the illustration. These sectors are being produced at the rate of one a day, and each one is built up from 45 silicon steel plates, is 10 ft. 5 in. high, 9 ft. 3 in. wide, and 12½ in. thick, and weighs nearly 20 tons. The accuracy and rate of production are unusually high for so massive a product, and it is interesting to note that the method of manufacture was not proven and the necessary plant was not available when the contract was accepted.

The high output required has necessitated a flow production line, and all the plant has been specially ordered or manufactured and sited for the one job. Because of the handling problems involved, all the operations have to have their own handling aids and lifting tackle, e.g., the whole of the preparation bay is served by roller conveyor, the shears have their own hoist, and the two cranes are used only for placing material on the start of the line and on to the trailer for removal. In the annealing and finishing bays, each operation has a crane, or a shift of crane time, allocated to it, with the exception of the ¼ in. shears and the D.R.N.S. stove, which have their own hoists.

Plate Preparation and Welding

When enquiries were first made about the fabrication of the magnet sectors from 1% silicon low carbon electrical steel, using ¼ in. thick laminations and ½ in. thick cheek plates, it was realised that two 5 ft. plates would have to be welded together, as it was impossible to obtain 10 ft. wide plates.

The ¼ in. and ½ in. thick plates are each marked for cast, ingot and position in the ingot, and are drawn from stores in such a way as to randomise any variations within each cast. Each plate is carefully inspected for thickness variation, lamination and surface defects, and the first operation on a pair of selected plates is to shear two edges at right angles prior to flame-cutting the rough profile of the magnet throat. A magnetic head working from a dowelled template controls the profile shape, which leaves $\frac{3}{16}$ in. for final machining.

The next operation, welding, presented a number of problems arising from the rigid specification, which called for weld metal of approximately the same chemical analysis and with 90% of the mechanical properties of the parent plate. The plates after welding must be flat, without any puckering; no undercutting at the edges of the weld and no thinning down of the plate would be permissible after the penetration and reinforcement metal had been removed by grinding.

To meet these requirements, a special electrode and an effective means of jigging were essential, and in a period of a few weeks the Quasi-Arc Company developed

Welding two 5 ft. plates together on the special purpose Fusarc CO_2 automatic welding machine.

a continuous electrode suitable for use with a Fusarc CO_2 process welding machine. In the early stages of production, trouble was experienced with transverse cracks and fissuring, attributed to the high silicon and low manganese content of the steel, but a satisfactory electrode was evolved which gave welds entirely free from cracks, and the weld metal analysis was approved by Harwell.

The Quasi-Arc Company also co-operated with Sankeys in the development of a suitable jig, which has a total clamping pressure of 60 tons, distributed to twelve individual pads of 12 in. length, the bed girder being capable of withstanding these forces without distortion. Four removable water-cooled copper backing bars were made with a camber for the correct amount of plate deflection to off-set welding distortion.

The close square butt type of weld preparation is used, and Fusarc 8 s.w.g. continuous electrode is used as the filler material with a current setting of 540A. at 28–30 V. The welding speed is approximately 17 in./min., and full joint penetration is achieved; the cambered copper backing bar is grooved ($\frac{1}{4} \times \frac{1}{16}$ in.) to assist in this connection. Close square butt joints are again used with the $\frac{1}{2}$ in. thick plates, one pass being made from each side. The plates are turned over for welding on the other side in a Sankey-designed special purpose manipulator.

Weld dressing is a two-stage operation in which a mechanised grinder takes off the gross excess, and the final finishing and polishing is effected by pneumatic hand tools using Tryolite 9 in. discs. Very close control is exercised to prevent undercutting below the plate surface.

Annealing

Annealing the plates, by heating stacks of them in bell-type furnaces to a temperature in the region of 800° C. and cooling them again, is carried out in order to flatten them to within $\frac{5}{16}$ in. over the whole area, homogenise the structure, and develop the optimum electrical properties.

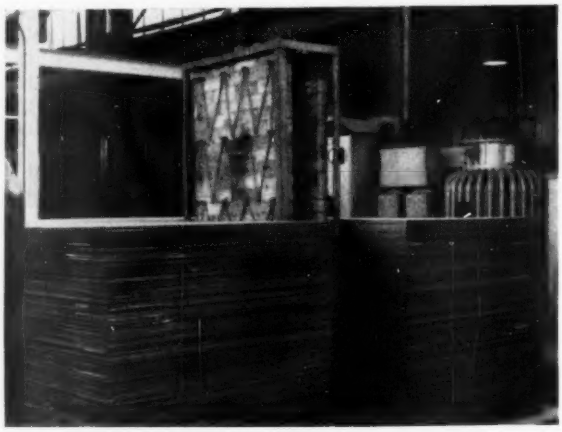
The size of these plates—roughly 10 ft. square—led to difficulties being encountered in the way of distortion, due to excessive temperature variations in a stack arising from too rapid heating or cooling. In order to discover the thermal pattern during heat treatment, as many as 26 thermocouples were placed in a stack of plates at various positions and the temperatures recorded.

An experimental anneal was carried out which took a month to complete, the charge being heated and cooled at a rate of some 3° C. per hour. This produced flat plates, but was much too slow for a production operation, and it was eventually established that flat plates could be produced with an annealing cycle of a little over a fortnight. The experimental work located the hottest and coolest parts of a stack of plates during an anneal, and the maximum permissible temperature differences in a plate at various temperatures during the cycle were established.

Another flatness problem arose from the fact that the plates, as received from the rolling mill, are slightly thicker at the centres than the edges, and to overcome this the thickness at six positions on a representative number of plates from each cast was measured and compensation allowed for this crowning effect. As the amount varies from cast to cast, tables have been drawn up for amounts of crowning ranging from 0·002 in. to 0·012 in. The actual compensation is made by inserting, at specific positions within the stack of plates, pieces of cold reduced strip 0·013 in. thick and in widths varying from 3 in. to 18 in. These in effect fit into the gaps on the edges of the plates and support them when they become plastic at the higher temperatures.

The furnace system finally developed comprises the elements on the four walls of the bell, the hearth elements, and a specially developed "throat heating block." These three heat sources total some 500 kW. and are controlled independently to maintain the thermal differences within the safe limits.

The insulated cooling cover has an air gap between the inner shell and the insulation layer. By operating flaps



A stack of magnet laminations ready for annealing: note the throat heating block being lowered into position.

at the bottom of the sides of the hood and on the outlets on the top of the hood, it is possible to regulate to quite a close degree the rate of flow of air through the gap, and so to govern the rate at which the temperature of the stack falls. It has been found possible to reduce the cooling time under this type of hood from five days to three days and so meet production rates.

The technique finally adopted involves stacking the plates on a flat base of 1 in. thick mild steel plate which is level to within ⅛ in. over the whole area of 100 sq. ft. The plates are stacked one at a time, together with the compensation strip, until a height of 4 ft. 3 in. is reached. The full charge, when completed, weighs approximately 80 tons. Twelve thermocouples are then placed in the charge and the throat heating block lifted into position. An inner cover of 17% chromium steel is then placed over the charge, forming a sand seal at the bottom. Into this is fed Hi-Nitrogen gas, as a protection against oxidation, during the whole annealing process.

Laminations on the randomisation beds after leaving the annealing furnaces.

The bell furnace is then placed over the charge and the temperature raised slowly at the specified rate. About eight days are required to reach the final temperature—in the region of 800° C.—and during this time the three sets of elements are automatically controlled by programme controllers. Cooling then takes place, firstly in the furnaces and then under the variable insulation cooling hood. The complete cycle from the placing of the furnace on the charge to the removal of the charge is about sixteen days, during which time some 20,000 kWh. of electricity are consumed.

Reference was made earlier to the importance of randomisation in the drawing of plates from store. Further randomisation is carried out after annealin completed sector must contain plates from at least casts, and these must come from at least four annea charges, with all three annealing positions (top, middle and bottom) represented, and all positions within the ingot included. The ingot positions follow automatically from the initial randomisation at the plate preparation stage.

From the annealing furnaces the plates are placed on the randomisation beds. There are fifteen beds arranged in three rows of five, and plates from any one cast are placed on a set of three beds. All the top sections of the various annealing charges are placed in one row of five beds, all the middle sections in another row, and the bottoms in the third row. A sector is drawn off the beds, using magnets on an overhead crane, by taking one plate of each pile in turn, going along the rows of five.

Shearing, Finishing and Insulating

After shearing the plates on all four sides, true and square to each other to a ± $\frac{1}{32}$ in. tolerance, the necessary holes are drilled, prior to surface finishing. Using an overhead crane fitted with lifting magnets, the plates are placed on a table standing 2 ft. 6 in. above floor level, and there an electrically operated sanding machine equipped with cloth-based silicon carbide abrasive is passed across the surface of the plate in two directions. The plate is then transferred to a second table for the deburring of all the holes and edges with portable sanders, before being turned over and the second side treated as the first.

After inspection the plates are placed in a steam coil heated soaking pit where, after 24 hours, they acquire a temperature of approximately 80° C. They are then removed singly and weighed; by using 42 or 43 ¼ in. laminations, with or without one ⅛ in. lamination, it is possible to control the sector weight to ± 252 lb. on a total weight of 41,944 lb. (18¾ tons).

The weighed plates are then passed through an automatic spray booth where an insulating coating of D.R.N.S. is applied to the top surface. The heat of the plates dries the coating and as they pass out of the booth the D.R.N.S. is hardened by the direct heat from gas jets. The D.R.N.S. coating is a Sankey development which can withstand temperatures up to 800° C. without adverse effect on its insulating properties, and which does not interfere with welding operations; it is not affected by water or transformer oil.

Building Operations

As there is a three-day building cycle, three building beds allow a continuous flow of work to be maintained. The first ½ in. plate is brought by overhead crane from the D.R.N.S. stockpile and the top and underside carefully inspected before being covered with insulating paper; narrow crown compensating paper placed along the two edges and varnished; and the necessary additional insulation coated with resin placed round the throat area. The other plates are treated in the same manner and placed one by one on top, finishing with another ½ in. plate. As each plate is added a resistance reading is taken between it and the preceding one.

Fourteen insulated tie bolts are inserted and tightened to 20 lb. ft. with a torque wrench. A shaped grid is then placed on top of the sector, 50 tons of weights distributed on it, and an electric heater placed within the throat to accelerate curing of the resin overnight. Sideplates are then welded in position, the tie bolts are tightened to 100 lb. ft. torque, and a rapid-curing resin is applied to the nuts to lock them in position. Work on the building bed completed, the sector is raised to an upright position and the few welds which were inaccessible on the building

Surface finishing the annealed laminations by means of a "floor polisher" type of machine.

On the nearest building bed the side plates are being welded on to the insulated laminations held down by 50 tons of distributed weights.

bed are completed. After spraying with grey paint, the sector stands eight days to allow temperature stability to be achieved before machining.

In the meantime the coil brackets and lifting lugs are fabricated as sub-assemblies by manual welding with rutile-iron powder electrodes, ready for welding to the sector after final machining.

Machining

The close tolerances called for necessitate strict control of all machining operations, and a rigid sequence has been established.

Each sector must age for at least eight days before any machining is attempted, to ensure throughout its mass a temperature constant to within 0·75° C. Any variation greater than this amount will cause movement in the extremity of the throat of up to 0·002 in./1° C. An allowance of 0·00025 in. has to be made on the 23·000 in. throat gap dimension for every degree above or below 20° C.

The minimum amount of clamping is employed, otherwise distortion takes place. Two fixed clamps only are used, all others being adjustable, and for the final machining of the active face the sector is held with scarcely any clamping at all.

Apart from the slot maching, for which a Clarkson slot mill is used, all operations are carried out with 14 in. diameter face cutters fitted with tungsten carbide blades. For rough machining the throat and for machining the $\frac{1}{2}$° taper on the rear of the sector, ten negative-rake blades are used, each blade being mounted progressively. For final machining the throat, seven positive-rake blades mounted in line are used. No burrs between laminations are permitted, since they would cause electrical short-circuiting, which cannot be tolerated under any circumstances. For this reason, a freshly-ground cutter is used for each sector.

Conclusion

When machining is complete and the coil bracket assemblies welded in position, the sector stands for twelve hours to allow the heat to dissipate before final painting and inspection, when a complete dimensional check is made. The machined surfaces are given a coating of strippable lacquer for protection during despatch and subsequent handling at Harwell, where the high standards of accuracy in manufacture of the sectors will be maintained in the geometric alignment of the magnet to maintain the plane of rotation during commencement and completion of bursts of protons.

Pera Council

At a recent meeting of PERA Council, Sir Basil R. G. Tangye, Bt., of Tangyes, Ltd., was elected Chairman of Council. Sir Basil succeeds Sir Lionel Kearns, C.B.E., Chairman and Managing Director, H. W. Kearns & Co., Ltd., Chairman of Council since 1946. Sir Lionel remains a Member of Council and of the Executive Committee of the Association. Mr. A. L. Stuchbery, Chief Technical Engineer of the Metal Box Co., Ltd., and Mr. G. R. Pryor, Chairman and Managing Director, Edward Pryor & Son, Ltd. were elected Vice-Chairmen of Council.

At the 14th Annual General Meeting of the Association, Sir William Stanier, F.R.S., was re-elected President of the Association, and the following were elected to Council: Mr. R. W. L. Fry, Managing Director, E. W. Bliss (England), Ltd.; Mr. R. W. Mann, Managing Director, Victor Products (Wallsend), Ltd.; Mr. G. E. Smith, Director of Production, F. Perkins, Ltd.; Mr. A. W. Vickers, Engineering Works Director, K. & L. Steelfounders and Engineers, Ltd.; and Mr. G. W. Wright, Technical Director, Asquith Machine Tool Corporation, Ltd.

Fretting Corrosion of Metals

By R. T. Allsop, B.Sc., Ph.D.

(G.K.N. Group Research Laboratory)

Damage resulting from fretting corrosion is observed in a variety of engineering components including bearings, switchgear and bolted or riveted joints. The present review examines first the nature and occurrence of fretting corrosion and then discusses the various theories which have been proposed to explain the phenomenon. In a further section the effect of varying such factors as humidity, duration, load, etc., on the amount of damage occurring during fretting is considered. Finally methods of eliminating or reducing fretting damage are suggested.

THE damage which may occur when contacting metallic, or non-metallic, surfaces undergo slight relative movement has been variously described as fretting corrosion,[1] friction oxidation,[2] and false brinelling.[3] The first reference to the damage associated with fretting was by Eden, Rose and Cunningham,[4] when they noted the appearance of the familiar brown debris on components of a fatigue machine. Other references to the subject were made in the years that followed, but it was not until 1927 that Tomlinson[5] made it the subject of an investigation. Subsequently, numerous other studies were made, amongst the most notable of which were those of: Fink,[6] Feng and Rightmire,[7] Wright,[8] Godfrey[9] Tomlinson, Thorpe and Gough,[1] Uhlig,[10] Feng and Uhlig.[11]

Feng,[12] has criticised the use of the term "fretting corrosion"; he argues that the available evidence suggests that the process is primarily one of mechanical wear, corrosion being only a secondary reaction confined to the wear product. It would, therefore, Feng suggests, be more realistic to use the term "fretting damage" or simply "fretting." Although it is considered that the objection raised by Feng to the term "fretting corrosion" is basically justified, it is now so widely used that it would probably be difficult to persuade authors to discard it in favour of the more realistic terminology proposed.

In the past, several definitions of fretting corrosion have been suggested, but as the knowledge of the process increases they tend to become inadequate. A definition which typifies many of those proposed in recent years is that of Waterhouse,[13] who defined fretting corrosion as the forms of damage which arise when two surfaces in contact and nominally at rest with respect to each other experience slight periodic movement. Feng,[12] whilst agreeing that fretting occurs under the conditions specified by Waterhouse, considers the definition to be inadequate, on the grounds that damage similar to that visualised by Waterhouse can occur as a result of unidirectional rubbing contact between surfaces which were nominally not at rest. As an alternative, Feng suggests that fretting corrosion be defined as a form of concentrated damage initiated by metal transfer and wear between two contacting surfaces whenever the rubbing conditions favour the trapping of wear particles. Considering the current views on the mechanism of fretting, this definition would seem to be more appropriate than that of Waterhouse.

Damage resulting from fretting corrosion is experienced by numerous engineering components. Examples frequently quoted include rotating shafts carrying press-fit members; the interfaces of laminated springs and those of plates riveted or bolted together, roller bearings in heavy equipment; and ball races of cars transported by road or rail. It has also been reported in electrical switchgear subject to vibration.

Fretting Corrosion in Dry Air

The mechanism by which fretting corrosion between metallic surfaces occurs has been the subject of extensive discussion and speculation for many years. The formulation of a comprehensive theory has, however, been considerably hindered by the lack of quantitative data. Although efforts to remedy this situation have increased in recent years, there remain numerous gaps in the knowledge of the subject which must be filled before the mechanism of fretting corrosion can be finalised.

The various processes which have been suggested to explain fretting corrosion are based largely on information available regarding ferrous materials; whilst, therefore, the views expressed below only relate directly to steels, it may well be that the principal features noted are also applicable to non-ferrous materials.

Ignoring differences of detail between the various theories of fretting, the main point which appears to divide the investigators in this field is the role of oxygen when fretting occurs in air. Waterhouse[13] is of the opinion that the repeated formation and removal of oxide films from the fretting surfaces is responsible for the bulk of the fretting damage, i.e. the process is essentially one of corrosion accelerated by mechanical oscillation. Uhlig,[10] who has treated the problem mathematically, is in agreement with Waterhouse to the extent that he accepts that the chemical corrosion aspect can result in an amount of damage which cannot be neglected. On the other hand, his own calculations show that for the most part it is a mechanical wear process which is responsible for the fretting damage which occurs.

Wright[14] and Feng and Rightmire[7] contend that the damage produced by oxide removal, as visualised by Waterhouse, is insignificant compared with that resulting from wear which is greatly accelerated by the presence of oxygen. The reason for the accelerated wear in oxygen is considered to be due to its ability to prevent continuous metal transfer between the surfaces, and to the abrasive oxide particles it forms with the material of the fretting specimens.

Although numerous other investigators have contri-

TABLE I.—EFFECT OF LOAD, SLIP, AND FREQUENCY ON FRETTING DAMAGE OF MILD STEEL; TOTAL TEST OF 67,800 CYCLES

Pressure Load (lb./sq. in.)	Frequency (c./s.)	Slip (in.)	Specimen Weight Loss (mg.)						
			Observed		Calculated				
			Corrected	Uncorrected	Total	Chemical Term	Mechanical Term	Chemical Wear (%)	Mechanical Wear (%)
500	540/60	0·0036	1·3	1·0	1·3	0·79	0·51	61	39
1,000	540/60	0·0036	2·2	1·8	2·1	1·1	1·0	52	48
2,000	540/60	0·0036	3·8	3·4	3·5	1·5	2·0	43	57
5,000	540/60	0·0036	7·5	6·6	7·2	2·1	5·1	29	71
5,300	56/60	0·0036	11·3	10·3	26·2	20·8	5·4	48	52
5,300	238/60	0·0036	9·8	9·1	10·3	4·9	5·4	29	71
5,300	540/60	0·0036	7·9	6·8	7·6	2·2	5·4	21	79
5,300	840/60	0·0036	5·7	4·9	6·8	1·4	5·4	14	86
5,300	1300/60	0·0036	5·0	4·0	6·3	0·9	5·4	10	90
5,300	2000/60	0·0036	5·3	3·3	6·0	0·58	5·4	7	93
5,300	3000/60	0·0036	6·6	3·2	5·8	0·4	5·4		
5,300	56/60	0·0091	32·7	30·0	34·4	20·8	13·6	61	39
5,300	540/60	0·0091	23·0	14·8	15·8	2·2	13·6	14	86
5,300	1300/60	0·0091	24·2	9·7	14·5	0·9	13·6	6	94
5,300	540/60	0·0004	1·1	1·1	2·8	2·2	0·6	78	22
5,300	540/60	0·0036	7·9	6·8	7·6	2·2	5·4	29	71
5,300	540/60	0·0067	15·1	11·3	12·2	2·2	10·0	18	82
5,300	540/60	0·0091	23·0	14·7	15·8	2·2	13·6	14	86

buted to the general theory of fretting corrosion, it is proposed in general to restrict the further discussion to a detailed analysis of the opinions of the workers mentioned above. This policy is adopted since it is considered that their views, in total, cover most of the possibilities regarding the mechanism of fretting corrosion.

Theory of Uhlig[10]

Uhlig has interpreted the facts available as indicating that there are two factors comprising fretting corrosion, one chemical in nature, the other mechanical. The chemical factor is concerned with the fact that as asperities of one of the fretting surfaces move over those of the other they remove the oxide layer, leaving a clean, active metal surface. This immediately reoxidises, only to be removed again by other asperities. There is thus the continual generation and removal of oxide films from the surfaces of the fretting components. The oxide removed constitutes the debris from the chemical component of fretting. In addition to removing oxide layers, projections from each surface will interact by the variously suggested mechanisms of wear to produce loose metallic particles. This, Uhlig considers as the mechanical component of fretting. Eventually the metallic particles will be oxidised.

Taking the above as a qualitative picture of fretting, Uhlig has derived mathematically an expression which relates the damage resulting from the chemical and mechanical components of fretting to such things as load, slip, frequency, etc. He has further compared the fretting damage between steel specimens under various conditions, as measured experimentally, with the calculated values. These are shown in Table I, from which it can be seen that, except in cases where small loads, frequencies or amounts of slip were used, the mechanical factor of fretting produces a large percentage of the damage occurring.

Although in general agreement between calculated and measured fretting corrosion damage is fair, the analysis has been criticised on several grounds. Perhaps the strongest of these is that the mechanism visualised by Uhlig is an over-simplification of the true process, in that, in practice, the mechanical and chemical components are intimately related and cannot reasonably be separated. Other objections have been raised against Uhlig's initial adoption of the logarithmic oxidation law and its subsequent approximation to the rectilinear law, and to the use of large amplitudes of oscillation which would introduce temperature and other effects not normally encountered.

Theory of Wright[14,19]

The mechanism visualised by Wright for fretting corrosion is based on the view that the process is one of wear which is accelerated by the presence of oxygen, the acceleration being brought about by the ability of oxygen to prevent continuous metal transfer and to form abrasive oxide.

Investigating the initial stages of fretting of steel by means of the electron microscope, Wright concludes that the initial damage is formed primarily by the ploughing action of what must be work hardened metal fragments transferred from the other surface. Debris is formed along and at the end of the tracks. Wright considers that during the continued fretting action the metallic part of the debris becomes roughened and distorted and fresh metal surfaces are exposed to the oxidising atmosphere. The final result is many minute oxide particles. The time required to complete the oxidation depends upon the size of the original particles, which is governed largely by the hardness of the original material; with many of the softer materials the particles are visualised as being of the order of 10 microns in diameter. Where the fretting surfaces are hard, the initial particles are small and the oxidation process rapidly completed.

Since, under fretting conditions, the amplitude of oscillation is limited, the fretting debris tends to be confined between the oscillating metal surfaces. Gradually an intermediate zone of debris is built up. This zone is considered to have two effects upon the fretting process. Firstly, it will reduce or prevent intermetallic contact between the fretting surfaces and, secondly, it will reduce the actual slip between the debris and the metallic surfaces.

The accumulation of oxide and the gradual loss of intermetallic contact means, it is suggested, that the wear process changes from one of metal transfer and ploughing to one of abrasion by oxide particles. The loss of slip at the surfaces of the bulk material means that the rate of fretting damage should decrease with time. Eventually, when the rate at which debris is formed is equal to that at which it escapes from the fretting area, the rate of fretting damage will become constant.

In support of the view of fretting damage expressed, Wright has described the results of electrical resistance

measurements made between two fretting steel surfaces, the experiments being based on the principle that as metallic oxide develops between the surfaces so will the contact resistance alter. During the initial stages of fretting, violent fluctuations in contact resistance were noted, these being ascribed, either to large amounts of unoxidised debris being formed, or to new points of contact between the surfaces being established. Following this period of fluctuation, the measured resistance became steady, suggesting that an oxide compact of constant thickness had been formed between the surfaces.

Theory of Waterhouse[13]

Waterhouse, while acknowledging the possibility that a mechanical wear process could be responsible for fretting in an inert atmosphere, has proposed that the bulk of the damage occurring in air arises as a result of a chemical process of the type suggested by Uhlig, i.e. the repeated formation and removal of oxide films from the fretted surfaces. Several investigators,[12,14] have objected to this theory on the grounds that it is inconsistent with the bulk of the data available. Thus, the results of Uhlig, for example, indicate that the chemical component of fretting in most cases constitutes only a small percentage of the total damage. Again, a theory of this type ignores completely the close relationship which, the evidence demonstrates, exists between the chemical action and the action of mechanical wear.

A further argument which has been advanced against the views of Waterhouse is that if the chemical process is responsible for the damage then no metallic particles should be detected in the debris. In fact, analysis has shown that metal is frequently present. Evans[15] has explained this apparent anomaly by suggesting that as oxide is removed so it removes with it adhering particles of metal.

Feng and Rightmire[7] have recently demonstrated that fretting corrosion (as measured by loss in weight) which occurs between steel test pieces in a CO_2 atmosphere is very similar to that occurring in air under otherwise similar conditions. According to the mechanism suggested by Waterhouse, the degree of fretting in CO_2 Feng and Rightmire argue, should be appreciably less than that in air, since the CO_2 constitutes an inert atmosphere. Waterhouse has countered this objection by suggesting that although reaction between steel and carbon dioxide at the temperatures in question was kinetically unlikely, it was none the less thermo-dynamically possible ; consequently, oxide films were probably being repeatedly formed on the surface of steel fretted in CO_2.

Theory of Feng and Rightmire[7]

The theory of fretting corrosion formulated by Feng and Rightmire has much in common with that proposed by Wright. Their views are, however, based on a conception of friction and wear which differs somewhat from that propounded by Bowden and Tabor[16] and others. According to Bowden and Tabor, weld junctions are formed between contacting asperities on metal surfaces. When the surfaces move relatively, shearing may occur at a junction or within either of the contacting metal surfaces. As Feng[17] has pointed out, such a process, although leading to metal transfer, does not give rise to the production of loose wear particles. He suggests that asperities which actually make contact are roughened by plastic deformation. The interlocking action of the roughened faces and the work hardening which results

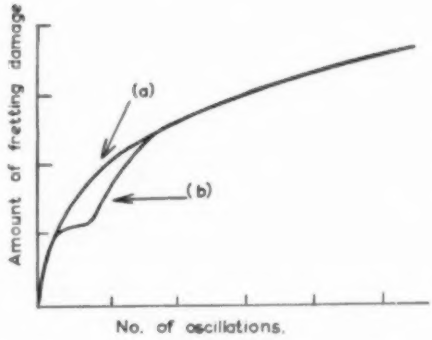


Fig. 1—(a) Monotonic fretting damage v. number of oscillations curve ; (b) form of curve suggested by theory of Feng and Rightmire[7].

from plastic deformation means that, when the surfaces move relative to one another, one of a pair of interlocking peaks will be sheared off at a point some distance away from the interface. If the temperature rise occurring during shearing, relative to the degree of surface contamination, is sufficient to cause welding of the sheared particle on to the remaining high spot, then metal transfer from one surface to another will occur ; if not, and providing the adhesive force is weak, the sheared particle will form part of the loose wear debris.

Analysing the results of their fretting experiments on steels in terms of the above views on wear, Feng and Rightmire suggest that the metal surfaces used, which had been prepared by emery abrasion, possessed, initially, an oxide film of the order of 50 Å thickness. When fretting is commenced, this oxide film prevents metal transfer and loose wear particles are formed. The freshly exposed metal resulting from the formation of wear particles acquires, in the limited time available, an oxide layer only a few angstroms in thickness. Such a thin film is unable to prevent sheared particles being welded to the remaining asperities, and so the process changes from being one of metal particle production to one of metal transfer. As the transfer continues, the number of asperities carrying the clamping load will increase, and so the load carried by individual asperities will decrease. Each is, therefore, subject to a smaller degree of plastic deformation during contact, and so the nature of the process changes from metal transfer to the production of loose particles. The accumulation of oxidised debris eventually results in the process becoming one of abrasion which, being more effective than shearing in producing debris, results in an increase in the rate of fretting. Eventually, as the layer of wear product accumulates and slip decreases, the abrasive action declines and a constant rate of damage is reached.

The mechanism of fretting corrosion proposed by Feng and Rightmire suggests that the relationship between fretting damage and the number of oscillations should, instead of being a monotonic curve of the type shown as (*a*) in Fig. 1, be of the general form shown as (*b*). Although earlier results by Feng and Uhlig and others have shown only the shape of (*a*), recently, Feng and Rightmire, studying the initial stages of the fretting of steels, have noted the discontinuity of curve (*b*) in Fig. 1. Further, they have shown, as their theory predicts, that the number of oscillations over which the plateau

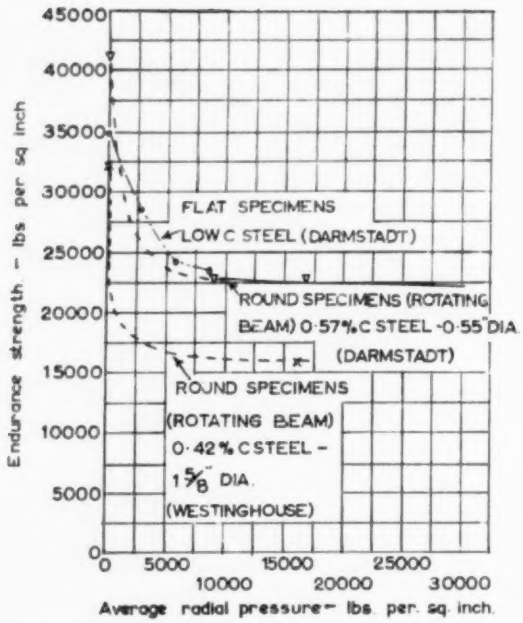


Fig. 2.—Effect of press-fit pressure on endurance strength (after Petersen and Wahl[20]).

extends depends on the extent to which the atmosphere inhibits metal transfer from one surface to the other.

Wright, acknowledging the possibility of a plateau in the early stages of the damage/time curve, has suggested two additional reasons why the damage rate suddenly increases after a period of little activity, viz :

(1) Transferred particles gradually oxidise and finally, after a period of time, are dislodged to become discrete wear particles.

(2) Repeated transfer of metal from one surface to another gradually builds into the surfaces thin oxide films, producing a zone mechanically weaker than the initial surface. After a given number of oscillations, the oxidised surface zone resists transfer and asperity interaction produces loose wear particles.

Which of these two mechanisms is more likely is, Wright considers, difficult to determine from the data at present available.

Assessment of Fretting Corrosion Theories

In reviewing the evidence available to support the various theories of fretting corrosion, it is apparent that neither the "corrosion" theory of the type propounded by Waterhouse, nor the accelerated wear concept of Wright and Feng and Rightmire, can be established as the correct process to the complete exclusion of the other. On the contrary, the evidence available suggests that both may operate simultaneously. The problem is, therefore, to decide whether the contribution of either of the two mechanisms is so small that it can be neglected. In the opinion of the author, there is nothing in the data available which suggests that the "corrosion" type of process plays anything other than an insignificant part in the fretting process. On the other hand, there is considerable evidence to support the "accelerated wear" theories which have been proposed.

Fretting Corrosion and Fatigue

Effect of Surface Damage

The well-established influence of surface condition upon the fatigue properties of metallic specimens suggests that the surface damage which occurs during fretting may affect the fatigue strength of specimens to which a dynamic load is applied concurrently with, or subsequent to, fretting conditions.

Essentially, fretting may produce two forms of surface damage, viz :

(*a*) If, as suggested by Waterhouse,[13] friction over the contacting surface is not uniform, the slip between the fretting components will, on a small scale, constitute a fatigue system, and there is the possibility that minute cracks will develop in the surfaces. Under fatigue loads of sufficient magnitude, the cracks will propagate through the section and eventually cause failure.

(*b*) The general roughening of the surface resulting from the removal of metal may give rise to stress raisers which will reduce the fatigue properties of the component.

Visualising the two possibilities noted above, Waterhouse examined fretted surfaces by visual, Talysurf and non-destructive crack detecting techniques. The magnetic powder method of crack detection failed to reveal any surface cracks of the type envisaged in (*a*) above. Visual and Talysurf examination showed that, in general, the surface cavities produced by fretting could be divided into two types—shallow dish-like depressions and small deep holes. Waterhouse suggested that the former resulted when abrasive oxide was able to escape from the initial point of attack between fretting surfaces. On the other hand, the deep holes would be formed when the debris was completely entrapped, abrasion continuing in a downward direction. A mechanism by means of which the pits formed in fretted surfaces are related to the entrapment of debris has also been suggested by Feng and Rightmire.[7] As a result of his investigation, Waterhouse concluded that the stress concentration effect of some of the deeper pits would be likely to result in a decrease in the fatigue properties of the material.

The precise effect of surface damage produced by fretting on the fatigue properties of steels has been investigated by Warlow-Davies,[18] using a two-stage experiment. In the first stage, the surfaces of the specimens were roughened by fretting, and in the second they were fatigue tested. It was found that fretting prior to fatigue testing reduced the fatigue limit of mild steel by about 13% and of alloy steel by about 18%. In contrast, Fenner *et al.*[19] commenting on early experiments at the National Physical Laboratory, have pointed out that there have been instances where fretting fatigue specimens have failed at points away from areas quite extensively damaged by fretting.

Effect of Clamping Load

Where both fretting and fatigue conditions are operative, the surface damage due to fretting is only one factor influencing fatigue strength ; another is the clamping load applied between the two fretting surfaces. Peterson and Wahl,[20] in their study of the fatigue properties of steel shafts carrying fitted members, have observed (Fig. 2) that increasing the press fit pressure reduces, at least initially, the endurance strength of the shafts. After the pressure has reached a value between 5,000 and

10,000 lb./sq. in., further increases have no effect on the fatigue properties. Similar results have been obtained (with a different experimental arrangement) for a titanium alloy by Liu, Corten and Sinclair.[21] Horger and Niefert,[22] in their investigation of various methods of fitting railway wheels on to axles, have noted that the more highly stressed shrunk-on wheels reduce the fatigue strength of the axles to a greater extent than pressed on wheels.

The results of the previous investigations into the effect of fretting damage and clamping load on fatigue properties do not indicate clearly which of these two effects is primarily responsible for the reductions in fatigue strength observed. There is an obvious need for further research into this aspect of fretting.

To be continued.

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Group's Expanding Research

In 1958 the British Oxygen Group had an average of nearly four British patent applications and over 16 foreign applications accepted for every month in the year. Illustrative of the spectacular and steady rise in the Group's research programme is the fact that the British Oxygen Group had 244 patent applications accepted last year, compared with 19 in 1950.

Nearly half of the Group's patent applications accepted last year emanated from British Oxygen Research and Development (BORAD) in Morden, Surrey, which serves the scientific and technical needs of the Group. Formed first as a department and later as a company, BORAD has extensive laboratories and a large specialist staff striving to improve present techniques, develop new uses, and create new products. In addition, some of the operating companies have their own experimental and research facilities.

Recent applications for patents concern such far-reaching developments as the use of oxygen and the suppression of fumes in steelmaking, and the Fusarc/ CO_2 automatic welding process, which is outstanding both for its ability to make horizontal-vertical fillet welds at great speed and for its deep penetration. They also include advances in computer cutting, electric welding, gas cutting and air separation, as well as oxygen and nitrogen equipment for aircraft. The applications also embrace such diverse developments as a gas-cutting nozzle, a stove using butane, new chemicals, paint, and advances in the preservation of virus specimens.

Large Impact Machine

The Admiralty has recently installed at the Naval Construction Research Establishment, Dunfermline, a large impact machine, which is capable of delivering 500,000 ft.-lb. of energy to a test specimen. This machine will be used to study the behaviour, under high rates of loading, of the various steels and welded joints used in warship construction. Although the primary use of this machine will be in connection with research for application in the construction of warships, it is expected that much of the information to be obtained will be of a fundamental nature, of value not only in other branches of engineering but also to steelmakers.

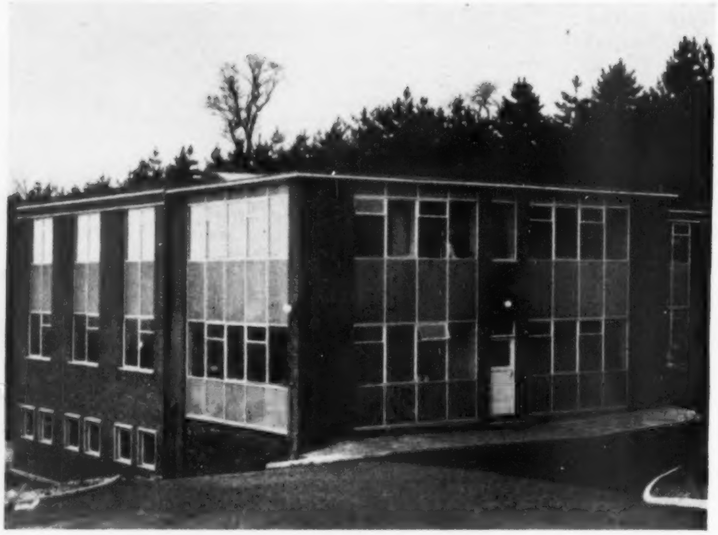
Consultants for the project were Professor J. F. Baker, O.B.E., F.R.S., Mr. A. M. P. Brookes and Mr. J. L. Reddaway of Cambridge University; and, in early design studies, Viscount Caldecote was also engaged. The machine was manufactured by Messrs. Fielding and Platt, Ltd. at the Atlas Works, Gloucester.

European Demonstration Tour

An ambitious attempt to show European countries the advances being made in electronic machine tool control systems and other industrial aids, such as closed circuit television, was launched by E.M.I. Electronics, Ltd., recently when a new demonstration unit left for Paris, venue for the Machine Tool Exhibition. Later, main industrial centres in Belgium, Holland, Germany, Switzerland and Italy will be visited.

Stressing the importance of the tour, which will cover the major European industrial centres, Mr. C. Metcalfe, Managing Director of E.M.I. Electronics, Ltd., says: "We in E.M.I. believe that in Europe as in other parts of the world, there is only one way to sell new ideas—by taking the products into the customer's own backyard and showing him how they work."

The trailer has been fitted out as a complete modern workshop. There is a programmer's office where punched tape is prepared to produce any type of workpiece—from a simple two dimensional template to a three dimensional die. Dominating the workshop area is a large Kearney & Trecker milling machine of an entirely new type, which is capable of carrying out the most complex operations controlled entirely from punched tape. E.M.I.'s machine tool control systems, which enable profiling and die sinking to be carried out direct from blue print to finished part by punched tape without the use of a computer, can now be fitted to machine tools manufactured by the world's leading companies. They provide one, two, or three dimensional control for any machine, operated either hydraulically or manually. Simple programming enables master cams, templates, models or finished parts to be produced easily. The giant American Cincinnati company has adopted the E.M.I. system, and Russian experts have already expressed great interest in it. Future plans for the unit include tours behind the "Iron Curtain".



The new Foundry Atmospheres Laboratory

B.C.I.R.A. Open Days

Interesting Display of Work in Progress

THE highlights of the first of the two Open Days at the Bordesley Hall headquarters of the British Cast Iron Research Association were the formal opening of the new building for the study of foundry atmospheres, which was performed by DR. J. G. PEARCE, C.B.E. (Director of the Association until the end of last year), and the formal inauguration of the new cupola installation by MR. E. PLAYER, C.B.E. (President of the Association). These items represent, of course, just two aspects of the work of the Association, and visitors to Bordesley Hall found much to interest them in the other laboratories.

Foundry Atmospheres

Before performing the opening ceremony, Dr. Pearce traced the Association's progress in the study of foundry atmospheres from the issue in 1947 of what is usually known as the Garrett Report to the present day. The Foundry Atmospheres Committee of the Association was formed in 1950, and soon established the policy that the most economical way of dealing with foundry dust was to trap it at the source and not allow it to contaminate the general atmosphere. The foundry atmospheres team which was formed, and which will occupy the new premises, has two parts, one providing an advisory service for member firms, and the other an experimental unit charged with the task of evolving designs for trapping dust at the source ; of formulating proposals for ventilating systems where this method is inescapable ; of testing and trying out prototypes ; and of conducting performance tests on equipment manufacturers' designs.

The policy of trapping at the source has borne fruit in the designs evolved for pedestal grinders, portable grinders, cutting-off machines, chipping hammers, de-coring bars and wire handbrushes. With the special fettling benches now available, this adds up to an impressive contribution. Work has also been done on moulding sand, both by way of keeping down dust and in taking care of dust arising in mechanical sand conveying systems. At the knock-out and the pouring station, an up-draught ventilation system takes advantage of the rising thermal currents. Substantial reductions in air volumes can be made when knock-out grids are enclosed by hoods and flanges, but such enclosures limit access to the grid, and investigations are in progress on up-draught and side-draught ventilation systems designed to provide adequate access to all four sides of the grid. In other instances, up-draught systems are best avoided, because dust generally arises below the operator's breathing zone and is best dealt with by a down-draught system.

The most acute problem is the jobbing shop, and especially the heavy floor-moulding shop without a common knock-out site, where moulds are knocked out at the moulding station, so that a general air-change system is necessary. Here collaboration between the ventilating engineer, the foundry planning engineer, and the equipment designer and manufacturer is of considerable importance, and in the Association the foundry operations planning team works closely with the foundry atmospheres team on new projects.

The Committee has sponsored two conferences to put information over to industry, one in 1951 and the other in 1955, the report of the latter providing the most comprehensive record of work in this field yet published. The team was called on by the industry, through the Joint Iron Council, to give evidence at the public enquiries in London and Edinburgh which preceded the arrangements under the Clean Air Act, and the results of these enquiries fully justified the effort involved.

During the period 1954-59, a total of £90,000 has been provided for this work from the Association's own resources, of which £25,000 has been spent on the new building. With these improved facilities, the team will have an opportunity of extending and enhancing the reputation it has achieved of being the chief authority in the U.K. on the production, dispersal and control of ironfounding dusts.

Melting and Casting

The role of the principal melting unit in the ironfoundry is likely to be filled by the cupola for many years to come, and a recent acquisition is a 30 in. diameter experimental cupola which can be operated with cold or hot

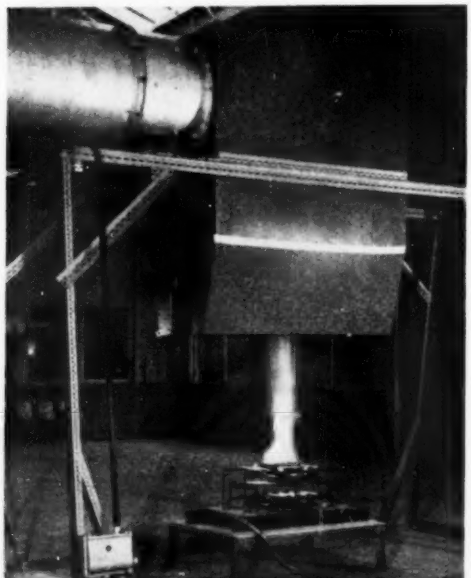
blast ; with or without water cooling ; and with acid, basic or neutral slags. This unit, which was described in detail in our last issue, will be used for studies on cupola operation.

A number of investigations are in progress on the soundness of iron castings, in the course of which it has been found that surface depressions or sinking defects which occur sporadically on light-sectioned castings are influenced by the degree of eutectic nucleation of the iron and the pouring temperature. A number of processes are being investigated by which the degree of nucleation may be reduced, with consequent improvement in soundness.

Studies of the soundness of ingot mould castings have shown that even in the most rigid moulds the wall thickness of the casting expands during solidification, and that the increase corresponds closely with the feed metal requirements. Keel block and 3 in. sphere castings provide sensitive test-pieces for the study of mould movement and casting expansion during solidification, and it has been shown that in all compositions of grey iron soundness increases as mould rigidity increases. This work has been largely inspired by the current belief that shrinkage in grey cast iron is largely the result of expansion of the casting.

The complicated shape of the K-bar test casting is believed to be one of the major factors influencing the shrinkage behaviour of this casting, and work is being carried out to study the casting dimensions, with the object of understanding the relationship between factors which influence soundness and the effect of the mould.

Other aspects of this work include a study of the effect of carbon content on the soundness of iron castings in green sand moulds, and the effect of solidification sequences on soundness.



Prototype bifurcated hood for studying up-draught ventilation of foundry knock-outs.

Plunging magnesium into molten cast iron.

Moulding

In addition to a comprehensive selection of routine sand testing equipment, the sands laboratories have available an apparatus developed by the Association to determine the volume and rate of evolution of gas from a baked core when heated, and equipment for the determination of the volatile constituents in a moulding sand, from which live coal dust can be calculated. The original radio frequency heater and stress-strain recorder developed by the Association to show the relationship between scabbing tendencies of a sand and its high temperature properties, which vary according to the additions made to the sand, is finding application in a study of the relation of high temperature properties of moulding sand to the types of coal dust available for use. Work is continuing on the design and construction of a higher frequency and higher power radio frequency heater than the unit so far successfully used.

A study is being made of the methods which may be employed to obtain sound castings from a normal green sand mould. Points under consideration include the use of high pressure moulding, the assessment of the term "rigidity" when applied to sand moulds, and the effects of various additions to green sand to improve the soundness of castings obtained. The fundamental properties of green sand are being studied in order to evaluate the characteristics that enable the mould to be rammed and subsequently stripped from the pattern.

Most of the factors influencing the properties of shell moulds have been studied, and the testing apparatus is now used as a method of controlling and assessing the properties of the sands and resins used in the process. It is intended to study the high temperature properties of shell moulding materials.

Other work in this section includes an investigation to establish the most suitable sand or addition to the sand to eliminate metal penetration if necessary in the CO_2 process.

Eutectic cell counting

Types of Iron

Foundry Iron—An interesting extramural investigation has demonstrated the possibility of producing low phosphorus foundry iron using only native iron ores as raw material. Oxygen blowing trials carried out on the 30 ton scale in the Kaldo high speed rotary converter in Sweden have shown that dephosphorisation of a high-phosphorus basic iron can be followed by recarburisation in the same vessel, and that the process is the most economical for producing low phosphorus foundry iron under present-day conditions.

White and Chilled Cast Irons—Among the investigations in progress on white and chilled cast irons are (*a*) one in which the solidification mechanism of white cast iron is being studied by means of cooling curves and quenching studies, and (*b*) another on microstructure and undercooling during solidification in relation to composition. The effect of the degree of nucleation on chill depth and mottle spread in chill test castings of varying size has been investigated, and the mechanism of mottle formation is being studied by thermal analysis, and the influence of trace elements on chilling tendency examined. The incidence of hot tearing in white irons is being investigated in relation to physical and chemical factors.

Factors controlling as-cast grain size in the 30% chromium irons form the subject of further experiments, and studies are in progress on the constitution and heat treatment of 27% and 33% chromium cast irons with varying carbon and silicon contents.

Malleable Iron—The influence of carbon, silicon and phosphorus contents on the mechanical properties of ferritic blackheart and pearlitic malleable irons produced under different heat treatment conditions is being studied, and special annealing facilities are being developed to provide annealed malleable iron test-pieces with a minimum of surface oxidation.

The aim of a study of the suppression of mottle in high silicon blackheart malleable iron is to improve the tensile properties and annealability, and experiments are being conducted to show that additions of bismuth and boron may be made to such irons to obtain completely white structures in heavy sections.

Graphite Formation—Work continues on an investigation to establish how graphite originates in cast iron—whether it forms directly by crystallisation from the melt, or indirectly due to breakdown of carbide. A correlation is being sought between graphite coarseness and the rate of eutectic cell growth, and the influence of composition on the number of eutectic cells and on the rate of growth at any particular level of undercooling is also being studied.

Gases in Cast Iron

Further investigations into the factors affecting pinholing in cast irons are in hand. These involve the effects of various additions to the iron, and of various mould treatments, and in the course of the work a number of industrial examples have been investigated. The effects of small amounts of various elements dissolved in ferro-silicon are under investigation, with the object of producing an efficient inoculant which will not increase the tendency of inoculated irons to pinhole defects.

Other investigations in progress in this field concern the effect of hydrogen on the graphitisation rate of malleable iron and its relation to other elements, together with the effects of preliminary heat treatment at 300–500° C.; and the relation between gas evolution during the enamel firing process and the incidence of " boil " in the enamel coat. No correlation has been found and a more practical approach is planned.

Mechanical Properties of Cast Iron

With a view to increasing the limiting temperature of 232° C. for cast iron for steam engineering applications to a more realistic temperature—probably about 343° C. —growth tests have been carried out in air at temperatures up to 500° C., for periods up to 64 weeks, and in steam at temperatures up to 427° C., for periods up to 49 weeks. No growth was found at temperatures below 400° C. Before the limiting temperature can be raised, creep data are required, and tests are at present in progress on an unalloyed flake graphite cast iron at 350° C. and 400° C.

Mechanical tests to find the effect of phosphorus on the general relations between mechanical properties, section size and chemical composition have recently been completed. Tests are in progress to correlate the mechanical properties of cast iron with eutectic cell size, and also to test relations established by other workers.

Corrosion

Two aspects of the corrosion of cast iron have been under investigation by the Association, namely, pitting of ships' propellers and corrosion of internal combustion engines by antifreeze solutions. With the support of the British Shipbuilding Research Association, field tests have been carried out to examine the effectiveness of cathodic protection against severe pitting attack in cast iron propellers. An effective measure of protection is given provided that electrical continuity does not exist between the shaft and the hull. Work continues to explain why some propellers require abnormally high current densities for complete protection, and to investigate the suitability of various coating materials to provide protection in ships where electrical continuity is present.

Evidence to date shows that the corrosion attack on

diesel engine waterways is caused by the accumulation of acidic oxidation products of the glycol in the coolant. It is probable that the formation of these products, the chief of which is formic acid, is accelerated by the loss of the copper corrosion inhibitor from the solution, and this loss is probably due to the corrosive effect of the amine present in the solution on the copper components. Work on the exact mechanism of the corrosion process in weak dilute acid solutions containing buffers is continuing.

New and Revised British Standards

METHODS FOR THE ANALYSIS AND TESTING OF COAL AND COKE

B.S.1016 PART 7 : 1959. ULTIMATE ANALYSIS OF COKE. PRICE 7s. 6d.

B.S.1016 PART 11 : 1959. FORMS OF SULPHUR IN COAL PRICE 4s. 6d.

IN the revision of B.S. 1016 : 1942, the series of analytical and physical tests are now being issued in separate parts, of which the first six have already been published. Parts 7 and 11 are now available ; and synopses of their contents are given below : Part 8–10 are in the course of preparation.

Part 7 deals with the determination by specified methods of the major constituents of coke, namely carbon hydrogen, nitrogen and sulphur. The Liebig method for carbon and hydrogen has been slightly modified in detail from that given in the 1942 edition ; furthermore, the use of oxygen only for combustion is now specified, particularly for a new high temperature (1,350° C.) alternative method. The macro Kjeldahl method for nitrogen has been excluded because of the difficulty of specifying the maximum time of digestion. Instead, a semi-macro method, using finely ground coke and a mercuric sulphate catalyst, has been specified. An improved Eschka method for sulphur has been introduced, and an alternative high temperature method has been added for use when numbers of samples have to be analysed, or when results are required urgently. In general—apart from the necessary modifications—the methods follow those already specified in Part 6 for the ultimate analysis of coal.

Part 11 deals with the determination of sulphate sulphur, pyritic sulphur and organic sulphur in coal. Here the classical method of Powell and Parr specified in B.S. 1016 : 1942 has been somewhat modified, digestion time for the hydrochloric acid extraction having been reduced from 40 hours to 30 minutes, and that for the nitric acid extraction from 24 hours to 30 minutes. It has been shown that an indirect calculation of pyritic sulphur content from the amount of pyritic iron present is more accurate than a direct determination. Organic sulphur is obtained by calculation, the sum of the sulphur and the pyritic sulphur being subtracted from the total sulphur determined as in B.S. 1016 ; Part 6.

ALUMINIUM ALLOY SECTIONS FOR MARINE PURPOSES (B.S.2614 : 1959) PRICE 12s. 6d.

REQUIREMENTS for two new series of aluminium alloy structural sections for marine use are included in this revised edition of B.S. 2614 : 1955. They relate to plain tee-bars for welding (from $1\frac{1}{2}$ in. × 3 in. to $5\frac{1}{2}$ in. × 8 in.) and plain bulb plates for welding (from 3 in. to 8 in.). The series specified in the 1955 edition—bulb angles for riveting, tee-bars for welding, (with bead), bulb plates for welding (with bead)—have been retained in this edition. A new dimension, an overall width for the bar, has been introduced into the tables for sections with bulbs ; and the symbols for all dimensions have been amended so that they are, as far as possible in line with those used in B.S. 1161 (Aluminium and Aluminium Alloy Sections). The tolerance tables from B.S. 1476 "Wrought Aluminium and Aluminium Alloys. Plate," which were included in the earlier edition, have been replaced by special tables of tolerances applying to each series of sections. Metric equivalents of all dimensions and tolerances have been calculated, and are included, for information, as separate tables.

BRITISH STANDARD FOR STEEL WIRE FOR COLD FORGED HIGH TENSILE BOLTS AND SIMILAR COMPONENTS (B.S.3111 : 1959) PRICE 4s. 6d.

Six types of steel wire suitable for the manufacture of high tensile bolts are specified in this new publication. They comprise : one carbon steel and five alloy steels—four of which are also to be found in B.S. 970, En Series. Chemical composition is specified for each type, and allowance is made for the selection of alternative carbon and manganese ranges to meet required hardness values. Mechanical tests are also specified, but maximum diameter is not. In some respects the standard is a relaxation of 2 S.100 "Inspection and Testing Procedure for Aircraft Steels" Section II), since there is provision for agreement between purchaser and manufacturer on a limit of decarburization.

Copies of these Standards may be obtained from the British Standards Institution, Sales Branch, 2, Park Street, London, W.1. (Postage will be charged extra to non-subscribers).

Distington Continuous Casting Division

DISTINGTON ENGINEERING CO., LTD., a subsidiary of The United Steel Cos., Ltd., has established a Continuous Casting Division which will specialise in the design and manufacture of continuous casting plants for both ferrous and non-ferrous metals. The Division is currently engaged in design work for a wide slab machine which is to be installed at Ste. des Fonderies de Pont-a-Mousson in France, and which will be capable of producing continuously cast slabs up to 50 in. wide and from 4 to 8 in. thick.

Distington is participating in this project and will design and build continuous casting plants on behalf of, and under licence from, Concast A.G., of Zurich, in which United Steel recently became shareholders. The personnel of Distington's Continuous Casting Division have been closely associated with the experimental machines which have been developed and operated by United Steel since 1952. This experimental work is still continuing, and the current programme includes the production of continuously cast slabs, 36 in. wide and 5 in. thick, and of 9 in. square billets. Killed, rimming and stainless steels have been cast successfully in these sizes, and rolled into high quality plate and strip.

Modern Ingot Mould Foundry at Dowlais

Completed during Bicentenary Year

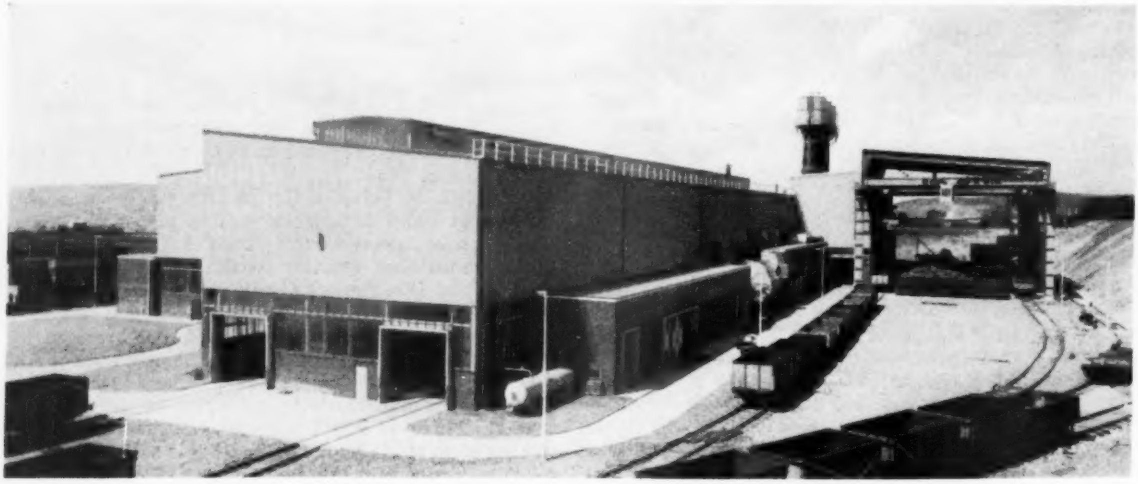
JUST two hundred years ago, a solitary blast furnace was built on a lonely Welsh hillside, and in 1760 John Guest left his home town of Broseley, Shropshire—where he combined the unusual pursuits of farmer, iron-founder, brewer and coal dealer—to manage the new furnace. Thus began the association of Dowlais with iron and steel, an association which was to bring world renown to the unknown Glamorgan village. The works then established pioneered many of the early processes of the iron and steel industry and made many of the rails for the great railway projects of the world.

By 1840 Sir Josiah John Guest—John Guest's grandson—was in charge of a works operating no fewer than eighteen blast furnaces. At that time the works was the largest in the world and, together with the associated coal mines, employed 10,000 workers. On the death of Sir John in 1852, control of the works passed to one of the few great women in industry, his widow, Lady Charlotte Guest. From 1856 until his death in 1882, the works was under the management of William Menelaus, and during this period the first Bessemer steel rail was rolled (in 1865), and a new rolling mill, twice as big as any in Britain, was installed. It is interesting to note that the Dowlais Company took out the first license for the Bessemer process little more than a fortnight after its announcement in August 1856.

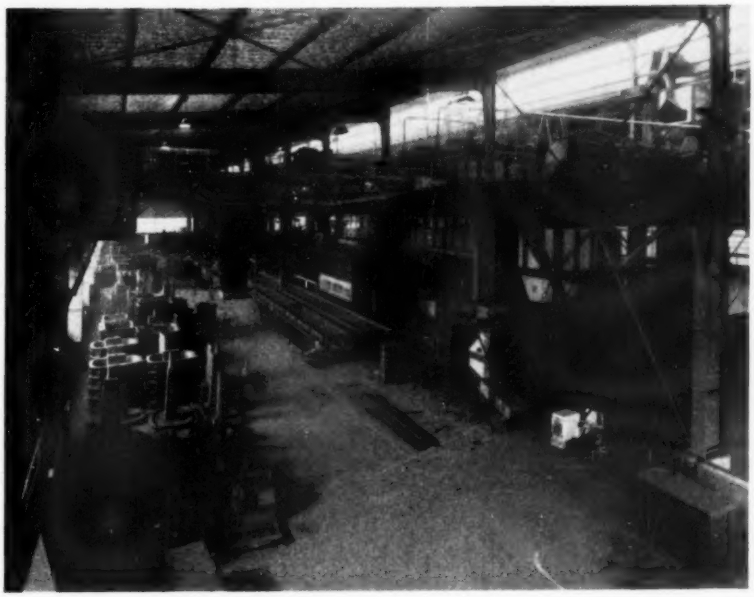
As local reserves of iron ore became exhausted, the works had to rely increasingly on imported supplies, and the company took the lead in forming the Orconera Company, at Bilbao, to ensure a supply of Spanish ore. A coast site had advantages for a works relying on imported ore, and the Dowlais company was one of the first to take the bold step of building a steelworks on the coast at Cardiff in 1888.

Down to 1900, the owners traded as the Dowlais Iron Company and in the ensuing two years became successively Guest Keen and Co., Ltd., and Guest, Keen and Nettlefolds, Ltd., as a result of acquisitions and amalgamations. The Lysaght works at Newport were later taken over by G. K. N., and in 1930 Guest Keen Baldwins Iron and Steel Co., Ltd., was formed by the amalgamation of the heavy iron and steel interests of G. K. N. at Dowlais and Cardiff, and of Baldwins, Ltd., at Port Talbot and Margam. Beginning in 1934, the new company completely rebuilt the Cardiff works for the comparatively modest sum of £3 million, and plans were later made for building a vast steel plant and wide strip mill at Port Talbot, but World War II prevented the carrying out of the project. After the war, the company became the biggest shareholder in the steel group that launched The Steel Company of Wales plant—the biggest and most up-to-date in Europe—at Port Talbot. The company was nationalised in 1951 and returned to private enterprise in 1954, becoming a wholly-owned subsidiary of Guest, Keen and Nettlefolds, Ltd., and taking the name of Guest Keen Iron and Steel Co., Ltd. In 1958, a further step was taken to safeguard the future when the company, jointly with The Steel Company of Wales, announced an iron ore terminal project for the Milford Haven area. This will provide deep water docking facilities for the giant iron ore carriers of the future, and enable ore supplies to be sent to the Cardiff works by small coasters.

Although steelmaking at Dowlais ceased in 1930, the company's foundry on the site of the historic Ivor works has been progressively expanded and modernised, and the latest expansion—the building of a new ingot mould foundry at a cost of £2 million—both marks the bicentenary of the company and gives proof of its confidence in the future of Dowlais.



General view of the ingot mould foundry with the stockyard on the right.



View of the moulding bay.

The New Foundry

The new ingot mould foundry is one of the most modern and best-equipped in the world. It has a weekly capacity of 1,000 tons—double that available previously—which could be increased considerably by shift working should it prove necessary in the future. All the ingot moulds for the Cardiff works will be supplied by Dowlais, together with half the moulds needed at the Port Talbot works of The Steel Company of Wales.

The excavation of some quarter of a million cubic yards of material was involved in the building of the foundry, which was completed in record time: work commenced on July 1st, 1957, and the first metal was cast on November 1st, 1958. The buildings are of all-welded portal frame construction and cover an area of 164,000 sq. ft., the casting bay measuring 560 ft. × 66 ft., the moulding bay 480 ft. × 66 ft., the middle bay 480 ft. × 37 ft., and the cupola bay 200 ft. × 40 ft. The last-named has adjacent to it a 190 ft. × 34 ft. stockyard with a capacity of 8,500 tons. Two 12-ton cranes serve the stockyard, a 7½-ton crane the middle bay, one 20-ton and two 30-ton cranes the moulding bay, and three cranes of 30-, 40- and 70-ton capacity the casting bay. Gantry rail cleats are stud welded, and all rails are held in position on rubber pads by rail clips supplied by G.K.N. (Cwmbran), Ltd.

Sand Plant and Moulding

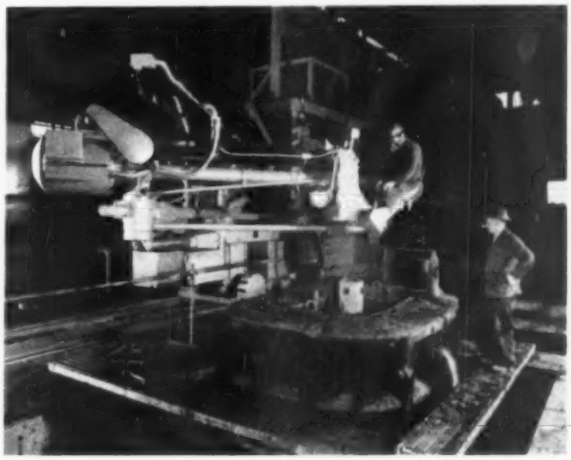
Sand is brought by road from Stourbridge and stored in a 500-ton bunker, whilst an adjacent 40-ton bunker is used for Fulbond, brought by road from Redhill. Moulding sand is prepared in 4,000 lb. batches, using two mills with a combined output of 38 tons/hr. A laboratory on the plant serves to control the finished product, which has a 9% clay content, a green strength of 4–5 lb./sq. in., a dry strength of 90 lb./sq. in., and a water content at the mill of 7%, which falls to 6½% at the sand slinger.

The travelling 50 ton/hr. capacity Beardsley and Piper Speedslinger used for moulding incorporates a sand plough on the feed belt as a special feature. The operator's seat is on the head of the machine and he controls all movements from that position as he travels round with it. A range of moulds is made, the finished mould weight being slightly greater than that of the ingot to be cast in it. A small 4-ton finished weight mould can be rammed in 10 min., whilst the largest, a 25-ton one, takes 40 min. The bottom plates cast in the foundry range from 1 to 8 tons finished weight.

The moulds are sprayed with blacking and dried in oil-fired stoves featuring overhead jets and a down-draught system. Fuel of 950 sec. viscosity is used to heat the stoves to 350° C. and the drying time is 12 hr. (overnight). Near to the stoves is a ladle drying station, where town's gas firing is used.

Metal Melting

The three specially designed cupolas are 95 ft. high (106 ft. from floor level) and have an overall diameter of 11 ft. The stack is lined to an internal diameter of 8 ft. with bricks supplied by G.K.N. (Cwmbran), Ltd., and the charging hole is 26 ft. above the bottom. Mechanical charging is used, and the metallics—consisting of hematite pig iron and scrap—are charged in 4-ton batches. Old ingot moulds form part of the scrap charged and reference may be made here to an interesting development at Dowlais in the breaking-up of such



Beardsley and Piper Speedslinger in operation.

moulds. The old method involved dropping a heavy steel ball from a great height onto the mould, but this gave rise to awkward corner pieces which were difficult to break further and difficult to handle. A new system has been developed which is much more efficient, and, incidentally, much more spectacular. In this, the moulds are placed in a depression in the ground and are then filled with water. An explosive charge is then detonated inside the mould, and fracture takes place at each change of section, with the result that the pieces left may readily be broken to a size suitable for charging to the cupola. At first sight this might seem a dangerous procedure, but there is less danger from flying pieces than with the old method: prudence demands, however, that one should keep out of reach of the huge column of spray which is sent up by the explosion.

View of the casting bay with the ladle drying station on the right.

At present the cupolas are operating on cold blast, but provision has been made for the installation of hot blast plant should it prove desirable in the future. Air is supplied through eight tuyères at a pressure of 45 in. w.g., and with a consumption of 14,000–16,000 cu. ft./min. a melting rate exceeding 30 tons/hr. can be achieved. The well can hold 10 tons of metal, and the cupola is tapped three or four times an hour, 8–10 tons being removed each time. A typical analysis is C 3·8%, Si 1·5%, S 0·06%, P 0·09%, Mn 1·0%, and the temperature of the metal at the spout is 1,340°–1,350° C.

Dust arresters of the wet type are fitted at the top of the cupolas, and the water from the arresters is used to granulate the slag from the cupola, which is tapped off every 35–40 tons. The water, dust and granulated slag pass to settling and dewatering tanks, where the slag and dust are extracted and sent to a tip, the water being recirculated after suitable treatment.

The cupola bottom doors are hydraulically operated, and a specially designed car receives the whole drop, the coke, sand and slag being quenched and the coke recovered. G.K.N. (Cwmbram), Ltd., bricks are used for relining and major repairs, and patching is carried out with gannister compounds.

Casting and Fettling

The molten iron is bottom poured from the ladle through a 3 in. nozzle, the teeming temperature being 1,240°–1,260° C. and the time for a large mould about 3 min. After casting, the moulds stand for about one hour for each ton of iron, following which the jackets are removed and the barrels pushed out by an ejector—a modified pile driver—in a matter of seconds, as compared with up to an hour using a 28 lb. sledge hammer. The barrels and boxes are returned to the moulding bay, and the moulds are cooled in sand for 2 to 7 days.

Following this slow cooling the moulds are cleaned on the shakeout before passing to the Hydro-blast station, where they are freed from sand with water at a pressure of 2,300 lb./sq. in. The time of de-coring varies from 25 min. for large bottle-top type moulds to 10 min. for small moulds. The wet sand is classified and reclaimed, the fines below 150 mesh being discarded and the rest returned to the sand plant for core making, using the CO_2 process. Suitable extraction plant is provided at all points where dust is likely to arise, such as the sand plant, cooling grid, and shake-out, the last-named being equipped with air curtains also.

Other Departments

The inauguration of the new ingot mould foundry has made it possible to concentrate on general casting production in the old iron foundry which has an area of some 60,000 sq. ft. and an output of 100 tons of jobbing and general castings a week. Individual castings up to 20 tons weight are made in B.S.1452 Grade 17 grey iron and in special alloy irons. A particular feature of this foundry is that large quantities of hot metal can be made available—up to 750 tons a week—for orders which require a minimum of moulding hours and a consequent large demand for iron.

For machining the bases of the moulds and the bottom plates, the foundry is equipped with a rotary planer and a drilling machine.

The 13,000 sq. ft. brass foundry has an output of some 3 tons a week, and is capable of making individual castings up to 2 tons in weight in copper and copper-, tin- and lead-base alloys, in addition to chill cast bronze bars up to 9 in. diameter and 2 in. diameter continuously cast bronze bars.

Other facilities at Dowlais include a pattern shop fully equipped with modern machines for the production of all types of metal and wooden patterns; a well-equipped machine shop; a structural shop where general engineering work, including the construction of overhead crane girders, is carried out; and a clay mill producing 500 tons a week of clay for furnace runners and blast furnace taphole clay.

Steel Industry Management Training

Residential College Established at Ashorne Hill

View of the mansion at Ashorne Hill.

ASHORNE HILL, the country mansion near Leamington Spa, has seen many changes during the last twenty years. During the war it was the headquarters of the Iron and Steel Control, and housed, in temporary accommodation built on the estate, some 600 members of the Ministry of Supply staff. Subsequently taken over by the British Iron and Steel Federation, it has served for several years as a convenient centre for conferences, both technical and otherwise, connected with the iron and steel industry. It has also served other organisations for the same purpose, and it is estimated that over 30,000 delegates have visited Ashorne Hill during this period. The latest phase in its history was marked by the recent establishment at Ashorne Hill of the British Iron and Steel Federation Management College, the culmination of several years' experimental work by the Federation in organising management courses, first on a regional, then on a national basis.

Aim of the Courses

The courses were originally proposed in a Report on Education and Training of Management in the Iron and Steel Industry approved by the Executive Committee of the Federation, and the aims were envisaged in the following terms :—

" Experience in the iron and steel and other industries has shown that if a man is freed from the daily affairs of his department and given the opportunity to review his technical and managerial problems, both with other managers and with experts in particular subjects, he can, comparatively rapidly, not only consolidate his knowledge and experience, but extend it and increase his personal effectiveness. It would, therefore, be of advantage both to the individual and his company if, before being promoted to departmental manager, a man were given the opportunity of attending a residential course organised within the industry on a national basis to give him the opportunity of :

(*a*) Drawing together the knowledge and experience he has gained piecemeal over a long period and viewing his own job in perspective ;

(*b*) Adding to his existing knowledge, information about the latest technical and commercial trends in the industry ;

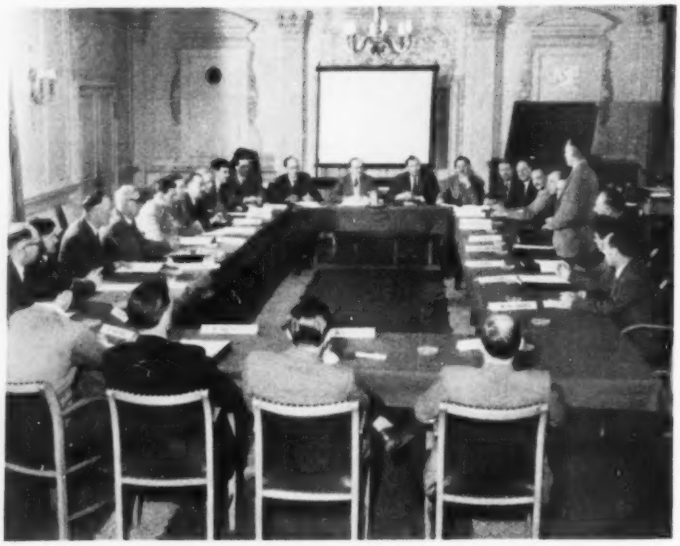
(*c*) Hearing and discussing the views of leading figures both from within and from outside the industry ;

(*d*) Developing his capacity for analytical and constructive thinking by studying and attempting to solve problems of particular current importance to companies in the industry ;

(*e*) Increasing his personal effectiveness by having individual practice in report writing, speaking and acting as the chairman, secretary and member of committees."

It was felt that such courses must be organised on an industry basis, since no company would have available at one time a sufficient number of men of suitable calibre. Moreover, it would be most valuable for those attending to have the opportunity of working with men of similar status from other companies. Finally, it was necessary to ensure that the ablest men in the industry participated in the conduct of the courses.

Management courses were and are seen as a logical and necessary step in a company's own plan for developing



The main conference room with a course in full session.

a manager. They can contribute to a man's capacity to manage, only if his previous and subsequent career in the company is adequately planned.

Scope of the Courses

The courses organised by the College to meet the needs of the industry are of two types. The first is of eight weeks duration, divided into two four-week periods with a ten-week interval. The second type consists of a two-week initial course, followed at a later date by two separate one-week courses. The difference between the two types of course is largely one of depth of treatment of the subject. The long courses provide more time for the discussion of inter-departmental problems, and are particularly suited to men from large works or large companies with interrelated works. The short courses, on the other hand, are designed mainly for men from smaller companies, and deal principally with rolling mills and finishing departments.

Each course is designed for twenty-seven members, broadly representative of the various functions of management in the industry. Nominations for membership are made by the companies, but selection for a particular course is made by the College authorities, taking into consideration the necessity to maintain a balance between the various aspects of the industry. An ideal course would comprise nine representatives from production departments, six from engineering and maintenance departments, three each from research and accounts departments, and six from such other departments as labour, welfare, education, sales, general offices, fuel engineering and traffic.

During the two years in which these courses have been in existence, the following branches of the industry have been represented: coke manufacture; ironmaking; steelmaking (open hearth, electric and Bessemer); section, rail and plate manufacture; wide and narrow hot and cold strip rolling; forging; bright bar and wire manufacture; tinplate manufacture; and tube manufacture. There have also been representatives for the Federation and the Iron and Steel Corporation, and from the Hindustan Steel Company, Durgapur.

The content of the courses and the methods of instruction are designed to stress the need for technical competence and for sound administration, to reveal the potentialities of new methods, and to clarify the broader issues confronting the industry and its management. To these ends much time is spent in considering problems arising from techniques now in use and from the development of new techniques; also in studying the economic factors affecting the industry, and its system of labour relations. The remainder of the time is devoted to more general problems common to all managers, and their implications for the iron and steel industry.

A valuable feature of the courses is the project work, which embraces technical development and organisation. Work planning, cost of production, maintenance and the economic use of labour are emphasised, together with the need for better communications and accident prevention. For this work the course members are divided into groups, or syndicates, and each group is required to submit a solution to the problems presented.

The details of the project naturally differ according to the type of course, but a typical one for a long course concerns an imaginary steel company, based either on an existing works or on a combination of different departments of several works. The members of the course are presented with a broad outline of the resources of the company in terms of plant, manning and finance, and are told that the board has in mind an output of 20,000 ingot tons per week as the future target. Certain additional information is given, such as the future availability of tonnage oxygen in the vicinity of the plant, the possibility of transferring ferro-manganese production elsewhere, etc., and the three specialised nine-member syndicates into which the course is divided are asked to examine in detail the steps necessary to achieve the required output from the point

Syndicate work in small groups plays a large part in the courses.

of view of (*a*) ironmaking, (*b*) steelmaking, and (*c*) rolling. During the course of this work, the syndicates are supervised by members of the directing staff of the College. Each project culminates in the writing of a report, which is presented to the course as a whole and to an assessor. The latter is a senior executive from the industry, expert in the field being considered, and his comments and the ensuing discussion are generally the highlights of the course. Subsequently, the integration of the revised departments into a balanced works, the revision of management organisation, the more effective use of labour, etc., may form the subjects of further studies.

Instruction and practice are given in chairmanship and effective speaking, in report writing and interviewing, in the elements of costing and accountancy, and in industrial engineering, including operational research, work study and statistical methods. Visiting speakers lecture on the economics of the industry; methods and application of research; labour relations and industrial law; and management problems generally.

The twenty-seven study bedrooms surround this quadrangle.

Study groups are formed to consider subjects chosen by the groups from a short list of topics such as air pollution, European Free Trade, planned maintenance, cost control, and wage structures. A library is available for background reading and for information on specific problems.

Case studies are concerned with people rather than with plant or processes, and members discuss difficult situations in order to stimulate thought and to further their understanding of such intangibles as co-operation, responsibility, authority and delegation.

Works investigations, which form an important part of the long course, take small groups of members to works for two or three days to consider current problems presented to them for solution by the works concerned. The groups collect and examine the relevant information and prepare brief reports suggesting lines of action. Representatives of the companies later visit the course to discuss these reports with the members.

Accommodation

Accommodation for members of the course is provided by twenty-seven study-bedrooms located in buildings surrounding an attractive quadrangle, complete with fountain. Each room has a working-size table, wardrobe accommodation, and washing facilities, in addition to which, each group of three or four rooms has its own bathroom. Meals are taken in the main dining hall.

The courses are no rest cure—involving as they do much hard work and study—but for the odd free period members have the use of such facilities as an open-air swimming pool, croquet lawn, badminton court, billiard room and television lounge.

Administration of the College

The Principal of the College, Mr. G. Smellie, formerly General Works Manager of the Steel Company of Wales, is assisted by a directing staff consisting of experienced men from various branches of the industry. A Committee, with Mr. C. H. T. Williams, Managing Director of Park Gate Iron and Steel Company as Chairman, and Mr. W. F. Cartwright, Assistant Managing Director of the Steel Company of Wales as Deputy Chairman, and an Advisory Panel under the Chairmanship of Mr. W. O. Campbell Adamson, General Manger of the Redbourn Section of Richard Thomas and Baldwin, ensures that close contact is maintained with the companies.

A glance through the membership of the Committee, and through the list of members of a recent course, shows that there is widespread backing for the scheme in the industry. There may be some firms, however, who are not yet convinced of the value of such training, or who consider it impossible for them to release key men for such relatively long periods. Each case must, of course, be considered on its merits, but enquiries recently made of the forty companies who have sent on the courses some three hundred men from seventy works have strongly confirmed their value. The British iron and steel industry at present employs some 300,000 people, and its middle and senior management number at least 6,000; its development plans are expected to add materially to this number. The potential demand for training at Ashorne Hill is thus considerable.

Copper Abstracts

CURRENT developments and new applications of copper and its alloys are of considerable interest to countless numbers of engineers, technicians, designers and other executive staff. Such people can read but a few of the many technical publications and similar items of literature, and the C.D.A., in order to draw their attention to the latest developments in the world of copper, now produce a publication each month which contains abstracts based on a survey of some 120 technical journals and other relevant media, supplemented by detailed reproduction from other abstract journals. It replaces the well-known C.D.A. Technical Survey. The subject matter, devoted exclusively to copper and its alloys, is classified under appropriate sub-headings, and each abstract is serially numbered for indexing in the December issue of each year.

Harry Brearley as a young man

Harry Brearley

An Outstanding Son of Sheffield

By Eric N. Simons

Said to have described himself as "the man who invented knives that won't cut," Harry Brearley was an outstanding 'character' in an industry which, by its nature, is productive of "characters." In this article, the author touches on some of the facets of the life of this gifted but unorthodox man of steel.

I FIND it difficult to believe that Harry Brearley is no longer with us. To me it seems only the other day that I sat in his pleasant room, examining the carefully classified ink-blots he had assembled in bound volumes, and listened to him as, in his attractive voice, bearing ample traces of its Sheffield origin, he explained their significance. Shutting my eyes, I can hear him now telling me that the only thing that mattered was one's own opinion, and that one should ignore the "experts" who sought to substitute a narrow, specialised knowledge for the overall wisdom and breadth of a well-read, thinking man.

He was one of the truest and most undeniable of Sheffield's sons, born a poor boy in Ramsden's Yard, which may legitimately be regarded in the light of the modern world as a slum street. It had eight houses, four on each of two opposite sides of a square. He was one of eight children, and he himself has said of his father that : "he was a good specimen of the country breed, spoiled in appearance by the hard, brutalising work associated, at that time, with iron and steel making ; and depreciated in manners by the drinking habits commonly practised by, and usually excused in, men who toiled and sweated at the hot furnaces." Brearley had always, however, the highest respect for his mother, and one of his first memories was of her and her eight children all huddled together in a living-room, 10 ft. by 10 ft., with only a couple of bedrooms above.

Fortunately for him, he was not born too early to reap the benefit of the then relatively new Education Act, and was sent to the type of elementary school considered good enough for children of his class. Of his schooldays he recollected nothing pleasant, and it is noteworthy that throughout his life he expressed nothing but contempt for the elementary school curriculum, though like so many elderly critics, he carried too far into his censure the recollection of his own unhappy schooldays. Things changed a great deal in the world of schoolteaching during Brearley's life, but he never appears to have familiarised himself with these changes.

When not actually sitting in the dingy, stuffy classroom, he turned an attentive ear and an observant eye to the teeming life of his environment. On washdays he turned the mangle for his mother—a job which I remember doing in my own childhood—wore clogs, was sometimes taken into the shopping streets to buy new clothes, and, like most Sheffield urchins, poked an inquisitive nose into any workshop in the district that presented a gap into which it could be thrust.

He was about to leave school when his parents removed to Carlisle Street, which Brearley said was "separated from hell only by a sheet of tissue paper." He now had to start earning a living, and his first job was to trundle coal over miles of cobblestones and sludge. Later, he helped to boil sweets in a backyard room. When the luncheon break came, he had to carry his father's dinner into the works, and sometimes he would sit for hours watching men at work on the puddling furnaces.

He tried various wage-earning jobs, without finding one that suited him. First, he worked in a shop. Then he did a boy's work in a stove grate factory, and lastly he worked in the private house of a doctor. From his relatively clean job, he passed to a steel works, where he became cellar-lad in a crucible furnace, doing "all the things a cellar lad should do, and some he shouldn't." The youngster seemed doomed to become yet another of the "mufflered gang" of Sheffield's East End.

Interest in Chemistry

The turning point of his career came when, dissatisfied, and deserting the steel works, he became bottle-washer in a chemical laboratory, the sole occupant of which was the chemist, James Taylor, whose idea for

keeping him out of mischief was to set him to work on exercises out of the "Irish National School Arithmetic." Brearley had first, however, to save the ninepence required to buy the book. When he had run through all these exercises successfully, showing unusual aptitude, Taylor taught him the rudiments of algebra, and this gave him an interest in study that he was never to lose. He began to attend night school, studied mathematics, pored over Channing's sermons, and began to learn shorthand.

But brainwork was by no means all that Brearley learned in the chemical laboratory. He picked up odd manual skills, such as wood-working, tin-working, glass-blowing and wire-working, and in his leisure hours made household furniture and practised leather-stitching. He stayed with Taylor until he was twenty, but his status was still that of a labourer. Fortune then smiled upon him. Taylor needed another assistant to replace one who had departed, and he told Brearley that if he could raise £50 as premium, he would take him on. A friend lent him the money without security and without interest, and he paid the premium by instalments.

The borrowed money was fully repaid within a year or two, largely by virtue of small increases in wages and exercises in cheap living. Taylor then emigrated to Australia, and Brearley found by this time that he was in love with both analytical chemistry and a young woman. He married, and the young couple took a cottage on the edge of the Derbyshire moors, paying a rent of 3s. 6d. a week out of the young chemist's wage of £2 a week. So poor were they that he made his own furniture, painted, stained, french-polished and upholstered it.

We have seen that among his hobbies were the making of domestic furniture and the soling of shoes, but he now acquired two further hobbies, the blowing of soap bubbles, and the "growing" of ink-blots. He had discovered that writing ink, if absorbed at a controlled rate by blotting paper, forms patterns characteristic of the particular ink employed, and some of these are strikingly beautiful. He wrote an article on this subject for the *Windsor Magazine*, and another on bubble-blowing as a physical exercise. The cheques he received for these contributions were the first fruits of his literary efforts.

Brearley had not lived and worked in the slums of Sheffield without thinking deeply about the social problems created, and he became convinced, like so many men of sincerity and goodwill in those days, that in Socialism alone lay the remedy. He became a minor official of the Independent Labour Party, but he was unfitted to open-air speaking and soap-box oratory made little appeal to him. His political activities, therefore, played but a small part in his life.

Once married, he turned seriously to the study of chemistry, but insisted that whatever he learned had to be confirmed at the bench. In those days laboratory work had not been mechanized. A great deal of skill and discretion were required in the routine operations, and the work had a certain glamour because so few of the works staff understood it. "Each operator," Brearley said, "had his allotted work and it was understood (in this particular laboratory) that any reliable simplification he introduced which saved time, gave him the privilege of doing what he liked with the time saved." By the exercise of his natural ingenuity, the young chemist was able to cut down his daily work to a couple of hours, which left him several hours a day, apart from

The young metallurgist at work

overtime, to devote to reading and experimental verification. During this period he invented an auto-pneumatic stirrer, and sold the selling rights in this to a dealer for a couple of guineas.

In 1898 he was offered an appointment in an Australian assay laboratory, and to qualify for this post studied the analysis and assay of white metals at the University of Sheffield, but dissatisfied with their tuition, he investigated these metals for himself. In the end he did not take up the Australian post, but his studies enabled him to work for typefounders and increase his slender income.

At thirty he had the local reputation of an expert solver of problems of analysis and a simplifier of analytitical methods for steel. He was offered employment by a steel firm in Sheffield, stayed with them for two years, wrote for the technical press, and wrote a book on "The Analysis of Steel Works Materials" in collaboration with a friend.

In 1904 he accepted an appointment in Riga, then, as now, incorporated in the Russian empire, and during the four years this lasted, he obtained, largely as a result of the Russo-Japanese war, invaluable experience in metallurgical practice and labour management. During this period he wrote his book "The Heat Treatment of Tool Steel."

The Discovery of Stainless Steel

Returning to Sheffield, he was invited to establish a research laboratory at a large steelworks, and accepted on condition that he should be free to work in his own way and keep his private consulting practice. The story of how he came to discover stainless steel is a long and complicated one, with many implications of chicanery and unfairness by the commercial men, and it will be for some future historian to disentangle the threads

and reveal the truth. All we need say here is that Brearley's work on high chromium steels was not inspired by an intention or expectation of discovering a stainless metal. He was merely studying problems relating to ordnance, and discovered that certain steels containing low carbon and high chromium could not be satisfactorily etched with either the usual or some new reagents. The use of the material for ordnance purposes aroused no interest, but Brearley reported on the unusual non-corrosive properties of the material to each firm with which he was associated. One of his reports suggested cutlery as a potential use, but no-one was impressed.

From the end of 1913 onwards, Brearley urged the usefulness of high chromium steel for cutlery, and actually some experimental knife blades were made, but almost certainly the cutlers concerned applied ordinary carbon steel technique to this new material, and failed, therefore, to produce satisfactory knives. They consequently condemned the new steel. Finally, Brearley himself bought some of the steel and successfully produced excellent knives. Unable to obtain what he considered fair treatment over his now acknowledged tremendous commercial discovery, Brearley resigned, and in 1915 became Works Manager of Brown Bayley's Steel Works, of which he eventually became a Director, receiving in 1920 the Bessemer Gold Medal of the Iron and Steel industry, the one distinction he ever coveted.

In 1925 he retired, but his activities by no means came to an end. In 1929-30 he spent a year in Australia and South Africa, after which the need for a superior climate to that of the bleak north led him to settle finally in Devonshire, though he frequently came up to Sheffield.

A Nonconformist

He was a man of extraordinarily forceful personality. Typical is this passage in a letter he wrote to me on 11th April, 1942: "Mind pictures are contrivances to think with, and they should fit a man like his skin. Some men (Clerk Maxwell) use the higher mathematics, and others (Faraday) the homely language of their fathers. But I mustn't scold you. . . ." The scolding was because I had deferred to the "experts" in a book I had written, and allowed them to amend my simple phraseology.

He wrote: "There is not much in the industrial use of pyrometers, etching methods and micro-observations beyond the grasp of the average intelligent workman; and when he sees distinctive bulls eyes scored by these means, he will adapt them to shop conditions, and in that case will better understand what the laboratory man is talking about. All useful observations, relating to the properties of metals, are not made most convincingly in a laboratory. Some can be better made at the scrap heap . . . A laboratory which rightly claims to be 'research' should not be hampered by routine work."

Every metallurgist is haunted by bogeys, but Brearley made fun of bogeys, and particularly of sulphur and phosphorus, the bogeys of the steel man. He said of heat treatment that it was not entirely a matter of clockwork and messages sent along wires, but a job for a man who took a live interest in his work and was able, when required, to exercise a judgment superior to clockwork indications. Most heat treatment operations, he claimed, were quite unnecessary, being merely crutches to help work, faulty in earlier stages of manufacture, past the inspector. It took time to get rid of the hospital atmosphere, and to replace it with the confidence in the enduring value of good work put into every stage of manufacture.

Brearley lived all his life as he wished to live, and his whole life, which ended in 1948, was redolent of that independent, sceptical, inquiring mind and critical forceful personality typical of the best of Sheffield. He was one of the few Sheffield-born men who have made important contributions to steel progress, and nothing serves better as a picture of the man than the following passage of his autobiography: "There is something in living men that is stilled when they die, which nothing less than a beheading operation can defeat. I own a trace of that something; that could support arduous service when enlivened by affection; could droop like a disappointed lover if nobody cared; and would kick like fury, unreasonably and foolishly, if it were ill-treated and could think of no other response."

Latin America's Refractory Needs

Mr. W. T. Hale of Thomas Marshall & Co. (Loxley), Ltd., on his return from investigating possibilities for refractory equipment in Latin America, made the point that, whilst there is an enormous potential for development, and foreign capital is badly needed, British credit terms are not sufficiently flexible to compete with those offered by Japan and Germany. Although the United States has been generous with capital aid, Mr. Hale received the impression that Latin American countries are glad to turn to other investors, and he feels that, could the British Government relax its credit terms, British investment would be welcome.

In the Argentine only two blast furnaces are in operation at present, but immediate plans include seven new blast furnaces, three of which are nearing completion, and Thomas Marshall hopes to benefit from the rapid expansion. In this country, particularly, inflation is a difficulty: in the last two years the Peso has dropped from 100 to 240 to the £. Efforts to halt inflation may bring about a recession, but Mr. Hale feels that iron and steel production will receive priority under any conditions. A market exists for British refractory equipment only until such time as local production has expanded sufficiently to meet requirements.

In Brazil, where Thomas Marshall received an enquiry to the value of £11,000 from Petrobras, the refractories industry is well established, and such imports as are encouraged are of a very specialised nature. Since Mr. Hale's return, Marshalls have received still further enquiries from this market for relining of blast furnaces. Twelve blast furnaces are at present in operation in the steel industry, and others in building, chiefly with Japanese and German capital. In Chile, Mr. Hale found a small steel industry equipped mainly with refractories imported from the United States. He was asked to supply quotations for equipment, and he feels there is a strong reaction against the established monetary benefactor, the U.S.A., and a welcome for new capital investment here as elsewhere in Latin America.

While British capital loan terms are as inflexible as at present, it is difficult for British industry to invest as widely as the potential in Latin America might warrant: however, Thomas Marshalls are aware of the possibilities open to them in the maintenance field immediately, and hopes to take advantage of any easing of credit restrictions in the future.

NEWS AND ANNOUNCEMENTS

Sheet Metal Shaping and Testing Colloquium

A Colloquium on Sheet Metal Forming, with special emphasis on Methods of Testing, organized jointly by the Société Française de Métallurgie and the International Deep Drawing Research Group (I.D.D.R.G.) will be held in Paris from the 23rd to 25th May, 1960, inclusive. Provisionally, the programme will cover:

Theoretical Studies of Sheet Metal Forming and The Materials Used in Sheet Forming—half a day.

Sheet Metal Forming—one day.

New Techniques of Sheet Metal Forming (Short Papers)—half a day.

Authors who wish to present a paper should send both the title and a brief summary to the Secretariat before the 1st November 1959. The exact programme may be subject to revision and the number of papers selected has to be limited. The organizing committee will decide on its choice of papers and the committee will inform the respective authors of its decision before the 1st December, 1959. The completed or provisional texts of the selected papers should be in the hands of the organizing committee before the 15th February, 1960. The text of the articles or papers must be in one of the three official languages, French, English or German, and should be prefaced with a brief summary in each of the three languages.

Offers of papers or requests for further information should be made to either member of the Joint Secretariat named below: S.F.M.—M. M. Dupont, Sécrétaire-General de la Société Française de Métallurgie, 25, rue de Clichy, Paris 9me; I.D.D.R.G.—Dr. S. Garber—B.I.S.R.A. Laboratories, Hoyle Street, Sheffield, 3.

Advanced Photography Scholarships

Kodak, Ltd. will award a number of scholarships annually to selected students of photography who have already reached a high standard, and who wish to devote a further year of full-time work to an advanced course of study. Six awards will be made in 1959, but in subsequent years the number may be increased to twelve.

Awards will be based mainly on the merit rating or marks obtained in the following examinations:—

(*a*) City and Guilds of London Institute Final Examination in Photography.

(*b*) Institute of British Photographers Intermediate Examination.

No entrance forms are needed. As soon as possible after the results of the examinations are available, both the examining bodies will furnish Kodak, Ltd. with a short list of students who have gained the highest marks or ratings, and a suitable number will be invited to meet a selection panel. At this stage they will be asked to provide any further personal particulars which are necessary. The final recommendations for awards will be made by this panel, which will consist of one member from each of these institutes and a representative of the Ministry of Education Kodak, Ltd., will be represented by an observer, who will not normally be concerned in making the final selection.

For the session 1959/1960 the successful students will be enabled to attend a full-time advanced course in Photography at the Polytechnic, Regent Street, London; but in subsequent years the scholarships may be tenable at other institutions where suitable full-time advanced courses of study are in operation. The awards will cover all course fees, the cost of approved text-books and necessary materials, and there will be a living allowance of £400 for the year payable in instalments each term in advance.

Polarographic Society Medal

A silver medal, to be known as the Polarographic Society Medal, has been designed, and will be awarded periodically in recognition of outstanding work in polarography, on the recommendation of a special committee. The first award has been made to Professor J. Heyrovsky for his discovery of the polarographic method in the nineteen-twenties, and for the subsequent major contributions to the subject by himself and his students.

Davy-United Reorganisation

As a result of the growth of the company, both in the range and volume of its products Davy-United have established a new group reorganisation in which the company formerly trading as Davy and United Engineering Co., Ltd., becomes the holding company of the group, with the new name Davy-United, Ltd. Two subsidiaries have been formed: the first—Davy and United Engineering Co., Ltd.—will carry on the main engineering activities of the group and will comprise the Glasgow Works, the Construction Division and the Darnall Works, with the exception of the workshops of the Instrument Division, which now becomes the second new subsidiary, Davy and United Instruments, Ltd., and is responsible for the development and manufacture of a range of electronic and radiation type instruments for the automatic control of rolling mills and other steelworks processes. The manufacture of rolls and steel castings will continue to be carried out at Billingham by Davy and United Roll Foundry, Ltd., which is also a wholly-owned subsidiary.

Russian Tinplate Experts Visit

Three leading Russian steel experts, specialising in tinplate, have recently completed a sixteen-day tour of British tinplate factories and laboratories. Leader of the party was Dr. S. P. Antonov (Deputy Chief Engineer of the Magnitogorsk Combinat), accompanied by Mr. D. I. Jasnikov (Chief of the Tinplate Department, Zaporozshe Steelworks), and Mr. V. A. Paramonov (Head of the Tinplate Laboratories at the Central Institute for Ferrous Metallurgy, Moscow).

The group spent some ten days in South Wales, visiting the Velindre and Trostre tinplate centres and the Port Talbot works of the Steel Company of Wales, Ltd., and the Ebbw Vale works of Richard Thomas and Baldwins, Ltd. A day was also spent at the Swansea laboratories of the British Iron and Steel Research Association. On their return to London, the Russian party made a one-day visit to the Tin Research Institute at Perivale, visited one of the London factories of Crosse and Blackwell, Ltd., to see the forming and making of tin con-

tainers, and toured the Battersea laboratories of BISRA.

The visit was organised by BISRA as part of the series of interchange visits arranged late in 1958 between BISRA and TSNIITCHERMET (the Central Institute for Ferrous Metallurgy in Moscow). It is the second to be carried out, the first being the British party on continuous casting which visited Russia in April last. The visitors had a series of discussions with British tinplate engineers and experts which were felt to be mutually valuable. They expressed their keen appreciation of British practice, and a number of contacts were made which should facilitate future exchanges of technical information and developments.

Plating Management Course

In collaboration with the Education Committee of the Institute of Metal Finishing, The Borough Polytechnic has arranged a course of six lectures on Plating Shop Management and Control, to be held on successive Tuesday evenings, commencing 6th October, 1959. Five of the lectures will be delivered by Mr. E. A. Ollard and the remaining one by Mr. A. R. King, of Vauxhall Motors, Ltd. Further particulars may be obtained from the Principal, The Borough Polytechnic, Borough Road, London, S.E.1.

Pilot Plant Research

The gap between metallurgical research on the one hand, and the industrial implementation of research results on the other, can sometimes be bridged by pilot plant investigations and demonstrations. The importance of such investigations has been increasingly recognised in India in recent years, and it has been decided to organise a Symposium on Pilot Plants in Metallurgical Research and Development, under the auspices of the National Metallurgical Laboratory. The Symposium will be held in the Laboratory, at Jamshedpur, next February, and invitations are being extended to engineers, metallurgists, technologists and research scientists to attend the Symposium and to contribute technical papers for discussion. Further details of the scope of the Symposium may be obtained from the Director, National Metallurgical Laboratory, Jamshedpur, 7, India.

Electric Melting Furnace Agreements

G.W.B. Furnaces, Ltd. have now concluded agreements for co-operative manufacture and sale, in Great Britain and most of the Commonwealth countries, of the whole range of melting plant designed by Demag-Elektrometallurgie, G.m.b.H. of Duisburg, Germany, and by the Lectromelt Furnace Division, McGraw-Edison Company of Pittsburgh, U.S.A. The total installed capacity of Demag and Lectromelt arc melting furnaces represents 6,750,000 kVA., corresponding to 2,800 installations. This agreement enables G.W.B. to offer arc furnaces with a capacity of up to 200 tons, with or without rotating shell, and alternative electrode control systems, these being static or rotating magnetic amplifier type, or hydraulic.

In addition, the agreement with Demag covers submerged arc furnaces for the reduction of ores and production of ferro-alloys and calcium carbide. Experience in this type of equipment is indicated by total connected loads exceeding 850,000 kVA. The field of induction melting furnaces is also well covered, enabling G.W.B. to offer Demag-designed crucible type units for mains frequency or motor alternator operation for steels, irons and non-ferrous metals. Channel type mains frequency induction furnaces may also be supplied for melting light metals, copper and copper alloys, zinc and iron.

Courses on Temperature Control

West Instrument, Ltd., manufacturers of temperature control instruments, are to give courses of instruction of one day's duration on the saturable core reactor. The first of these are to be held on the 14th and 15th October at the Company's London Office. A brief summary of the theoretical background of the saturable core reactor will be given to those attending the course. The saturable core reactor forms the basis of the stepless temperature controller, an instrument claimed to be superior to both the on/off and time cycling proportioning controllers.

The lectures will be informal, and a proportion of the time will be devoted to discussion and the answering of questions. Executives who are interested are invited to write to Mr. J. Hartnett, West Instrument, Ltd., 52 Regent Street, Brighton 1, Sussex.

Scottish Strip Mill Contract

The order for the building, at a cost exceeding £4 million, of the 68 in. semi-continuous hot strip mill for the Ravenscraig Works of Colvilles, Ltd., has been placed with Davy and United Engineering Co., Ltd., Sheffield. The new mill will comprise a 42 in. vertical edging scalebreaker, a 44 in. × 68 in. horizontal scalebreaker, a 39 in. and 56 in. × 68 in. reversing roughing mill, with attached 33 in. vertical edger, a rotary crop shear, a 28 in. and 56 in. × 68 in. six-stand finishing mill, two downcoilers and coil unloaders, and associated roller tables and ancillary equipment.

When the new mill goes into production it will have an initial output of 500,000 tons of strip steel products a year. It is, however, being designed to provide for an eventual output in excess of 1½ million tons a year. More than 47,000 h.p. will be needed to drive the mill, which will produce strip and light plate from 24 in. to 60 in. wide, in coils weighing up to 40,000 lb.

The contract will have an immediate impact on Scottish industry, for Davy-United's Glasgow Works will undertake a substantial part of the design and manufacture of the 9,000 tons of machinery involved. Colvilles, Ltd., are themselves building a 52 in. × 138 in. slabbing mill which will supply the heavy slabs required to feed the hot strip mill.

I.B.F. Office Moves

The head office of the Institute of British Foundrymen will be transferred from Manchester to London on 13th November, 1959. The new address and telephone number will be 14, Pall Mall, London, S.W.1. (WHItehall 7141-2). Communications posted after November 12th should be sent to the new address.

Instrument Distributors

The recently formed Analytical Instruments Department of Southern Instruments, Ltd., Camberley, has appointed A. R. Bolton & Co., of Edinburgh, as sole distributors for Scotland.

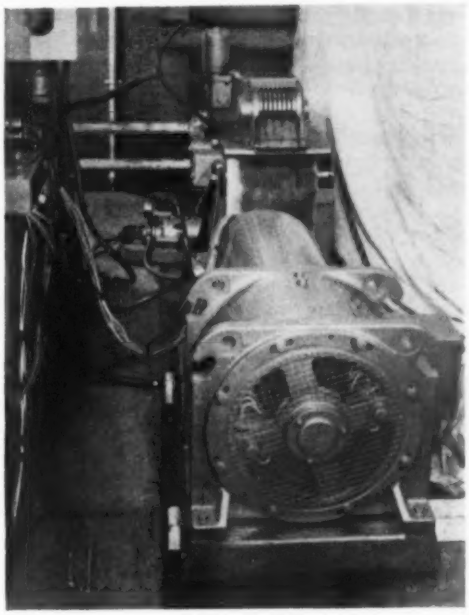
RECENT DEVELOPMENTS
MATERIALS : PROCESSES : EQUIPMENT

Cathodic Protection for Auxiliary Heat Exchangers

An ingenious yet simple means of preventing corrosion in auxiliary heat exchangers, small condensers, etc., is now being manufactured in this country. The Galvion anode, of which there are three sizes, comprises a brass plug with B.S.P. tapered threads, and a number of high purity zinc " bobbins " or elements having a threaded centre steel core. The elements can thus be screwed into each other to allow adjustment of length to fit confined spaces without waste, and an interference thread ensures vibration-proof service.

It is only necessary to drill and tap the cover of the spaces to be protected, the tapered plug thread ensuring a watertight joint without the need for sealing compounds. Existing drain plugs can often be used. Thus simple fitting and even easier renewals help to ensure that the protection is maintained and full benefit is received. It will be seen that there are many applications, both marine and industrial, to which these anodes can be applied. In the past the labour of renewing protective blocks secured to the inside of end box covers, or the drilling out of expended zinc pencils from plugs, has often led to the protection being neglected, with resultant shutdowns and renewals.

F. A. Hughes & Co. Ltd., 4 Stanhope Gate, London, W.1.



The rotary impulse generator gives a pulse rate of 400 per second at a peak output of 250 A.

Spark Machining Equipment

The Sparcatron R.I.G. spark machining equipment has been developed primarily as a roughing unit, as its rate of stock removal is in the region of 10–20 times as fast as the standard Mark III machine, depending, of course, on the material and area of the electrode used. Many types of material may be used for electrodes, including brass, copper, aluminium and Mazak, and, despite the rapid stock removal, electrode wear is stated to be surprisingly low.

The equipment consists basically of the normal Mark III machine head, working in conjunction with a rotary impulse generator (hence the initials R.I.G.) and a control cabinet, the latter being provided with tappings for power supplies in the ranges 200–250 V. (10 V. steps), 240–440 V. (20 V. steps) and (for the Canadian market) 600 V. It is suitable for 50 or 60 c/s. A pulse frequency of 400/sec., at a peak output of 250 A., is provided by the special generator, which thus permits the machine head to remove stock at the rate of approximately 4 cu. in./hr., using brass, copper or Mazak electrodes. The rate of wear for copper or brass electrodes is in the region of 0·3 in./cu. in. of stock removed.

When the R.I.G. equipment is used in conjunction with the standard control cabinet, the changeover from roughing to finishing of work can be achieved by the simple operation of a switch. Where the Sparcatron Mark III equipment is already installed, only the impulse generator and control cabinet are necessary to enable advantage to be taken of the new techniques.

Because of its high rate of stock removal, coupled with the possibility of machining a greater area and depth than usual, the equipment is well suited to the production of large forging dies and the like.

Burton, Griffiths & Co., Ltd., Mackadown Lane, Kitts Green, Birmingham, 33.

Re-styled Box Furnaces

The re-styling of the Birlec range of standard box furnaces has resulted in improved appearance, rationalisation of manufacture, and reduction in price. The G.P. 1000 range includes five furnaces suitable for operation at 1,000° C. and ranging in capacity from 1·5 cu. ft. to 26 cu. ft., and in rating from 20 kW. to 70 kW. In the three smaller sizes, the resistance elements are supported in the side walls by specially formed refractories, and in the larger sizes they are supported from the roof, to provide for handling heavy and bulky work without the risk of element damage. Compensation for door losses is provided by an element on the inner face of the door. The G.P. 1000 furnaces have cast nickel-chromium alloy hearth plates, but for exceptionally heavy work the two largest sizes can be supplied with a hearth of refractory brick.

In the G.P. 1400 range—suitable for use at temperatures up to 1,400° C.—the four furnaces range from ¼ cu. ft. to 3 cu. ft., and from 16 kW. to 60 kW. They are heated by silicon carbide rods mounted transversely below and above the hearth, and the hearth plates are also of silicon carbide.

On all G.P. furnaces the door is hand or wheel operated and fully counter-balanced. Power operation is available

as an optional extra, using a foot-operated compressed air system. The heating elements are automatically isolated from the power supply when the door is opened. The control cubicle is equipped with a temperature controller, main isolating switch, control and safety contactors, and there is provision for the fitting of a temperature recorder if required. A gas inlet connection is provided at the back of the heating chamber so that a protective atmosphere can be used where necessary.

Birlec, Ltd., Tyburn Road, Erdington, Birmingham, 24.

Speed Regulator Air Cylinders

BALDWIN INSTRUMENT CO., LTD., have announced a new speed regulator, for use with their compressed air cylinders. These new units are an improved development of the earlier micrometer type, and have a regulation of at least 3 times that of the previous model: the bore sizes are $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, and 1 in. The new speed regulator is slightly larger than, and utilises the same two-piece construction as its predecessor: it is made from anodised duralumin. A friction device incorporated in the body of the regulator prevents the micrometer adjustment from being disturbed by vibration.

Where the speed of movement of an air cylinder is required to be different in each direction of movement, the new Baldwin speed regulator is a simple means of producing this. The regulator screws directly into the exhaust ports of the directional control valve, and thereby throttles the escape of air from the exhaust end of the cylinder. Where steadiness of motion is required, this method of speed regulation is to be preferred.

Baldwin Instrument Co., Ltd., Brooklands Works, Dartford, Kent

Improved Flow Metering

HONEYWELL CONTROLS, LTD., have recently raised flow and liquid level metering accuracies by installing a new high-performance diaphragm on their differential converter transmitters. The "pneumatic balance" differential converter, which previously contained a Fluon-coated diaphragm separating high and low pressure chambers, now uses Viton as a diaphragm coating. Honeywell's production engineers have found that the new diaphragm provides better long-term stability of measurement and higher stability under varying temperatures. The chemical resistance of the new diaphragm is good, and it can be used to meter alkalies, amines, hydrocarbons, and dilute or concentrated mineral acids. The Teflon coated diaphragm remains available as an option for metering substances which might attack the new diaphragm.

Honeywell Controls, Ltd., Ruislip Road East, Greenford Middlesex.

High-Speed Flash Tube

A NEW range of high-speed cathode-ray flash tubes which produce a flash of the same order of intensity as a gas-filled electronic flash tube, such as is used in photography, has been introduced by the Electronics Department of Ferranti, Ltd. These tubes, known as the CL60 and CL70 series, light up all over simultaneously, in contrast to the normal behaviour of the cathode-ray tube, and have the additional advantage that flashes can be repeated much more rapidly. Flashes of up to one million per second are obtainable. It is also possible to produce long flashes, and flashes which contain an internal fine structure consisting of a multiplicity of smaller flashes.

The new tube is likely to be of value as a high-speed stroboscope and in high-speed photographic work; in the operation of high-speed photo-electric devices requiring short flashes of light, and for time-marking on films and in Xerographic processes. Another possible use for the tube lies in the measurement of short intervals of time or electrical pulses which occur in a random manner. The lamp can be arranged to flash at the beginning and end of a given interval of time or pulse. Alternately, two different coloured lamps could be used to mark the beginning and the end.

Electronics Department, Ferranti, Ltd., Gem Mill, Oldham, Lancs.

Radiation Monitoring Film

THE new Kodak radiation monitoring film provides an efficient method of assessing the exposure of personnel to X-rays and gamma rays. Two emulsion layers of different sensitivities are coated one on each side of the film, and the total density produced on both emulsions together is used to measure small quantities of radiation. If, as a result of large quantities of radiation, the density of the film is too high for measurement, the more sensitive emulsion can be stripped from the base, leaving the less sensitive emulsion intact for measurement. Two ranges which overlap slightly are thus provided. Each film is supplied in a separate light-tight packing and is ready for immediate use.

Kodak, Ltd., Kingsway, London, W.C.2.

Diamond Abrasive Wheels

FELKER Di-Met diamond abrasive wheels are now available in this country from Shandon Scientific Co., Ltd. The Type D.I.T. metal bonded wheels are available in thicknesses from 0·006 in. to 0·020 in., with flush blades 2 in. to 5 in. in diameter, and diamond depth $\frac{1}{16}$ in. or $\frac{1}{8}$ in. These five blades are particularly valuable in the electronics industry for the slicing, dicing and wafering of such materials as quartz, germanium and silicon. The Type D.I.T.R. wheels—available with metallic or resinoid bond—are specially produced for the cutting of semi-precious stones, glass, ceramics, tungsten carbide, etc. In this type, the blades are relieved at the side, and the size ranges from 3 in. to 14 in. diameter, and 0·025 in. to 0·062 in. thick: the diamond depth is $\frac{1}{16}$ in. or $\frac{1}{8}$ in. Both types are available with a wide variety of grit sizes and arbor holes, and the concentricity is accurate to within 0·001 in.

Di-Met Rimlock wheels—a third type—are low-cost diamond abrasive wheels for the rapid cutting of hard, brittle non-metallic materials, with many useful applications in the ceramics industry, and in geology, minerology and petrology. The sharp-edged diamond particles are locked in the wheel rim, and the wheels—for wet operation—are available in diameters ranging from 3 in. to 36 in., and with arbor holes to fit any machine.

Shandon Scientific Co., Ltd., 6 Cromwell Place, London, S.W.7.

CURRENT LITERATURE

Book Notice

STATISTICAL SUMMARY OF THE MINERAL INDUSTRY : 1952–57

PRODUCTION—EXPORTS—IMPORTS

Royal 8vo., 377 pp. prepared by the Mineral Resources Division, Overseas Geological Surveys, and published by H.M. Stationery Office. 27s. 6d. net.

THE Statistical Summary of the Mineral Industry is an annual publication of statistical tables covering a period of six years, showing world production, exports and imports of all the important economic minerals and metals. The present edition covers the period 1952 to 1957.

Production tables for cobalt, copper, lead, tin and zinc show not only the output of relevant ores in terms of metal, but also give figures of metal production. So far as possible, the latter tables give the amount of primary metal obtained, showing separately, wherever important, production of secondary metal. Thus it is possible to see at a glance the amount of new metal available in any year.

The sections on coal and petroleum are very comprehensive, including statistics of the production of and trade in by-products and refinery products. As the unit for these fuels is the same, comparison is facilitated. Statistics for all the principal non-metallic minerals are also included.

It is claimed that this reference book contains more information on world exports and imports of minerals and metals than any other publication, including as it does not only the crude material, but details of the chief semi-manufactured products, refinery products and other derivatives.

PROCEEDINGS OF A SYMPOSIUM ON ALUMINIUM IN PACKAGING—JUNE 1958

188 pp. 8 vol., numerous tables and illustrations. Published by The Aluminium Development Association, 33, Grosvenor Street, London, W.1. 15s.

ANY discussion which concerns consumer goods is likely to have its human interest, and that on the papers presented at the Aluminium Development Association's Symposium on Aluminium in Packaging—held at the Savoy Hotel in June of last year—is no exception. One can, for instance, find comparisons between the tastes of beer drinkers in this country and the United States, and a reference to the pre-packed television dinner available in America, which is heated and served in its aluminium foil tray, the latter being subsequently discarded. Customer appeal is, of course, a matter of prime importance in the choice of a packaging material, but it is not the only criterion. Cost, passivity towards the product, protective capacity, versatility in manufacture, and ease of disposal are all factors which must be taken into account, as was emphasised in the papers presented and the ensuing discussion on them.

At the first session, three papers were presented which dealt with the economic aspects of aluminium as a packaging material, its characteristics for this purpose, and the design of aluminium packs. The papers presented at the second session were of a different nature, in that they dealt with specific uses on which there had been greater or lesser commercial experience, namely cans for processed food, general line containers, collapsible tubes, foil and aluminium closures.

Although the papers and discussion were confined to one aspect of the subject—the non-returnable container or package—a wide variety of applications was involved, and this was reflected in the variety of interest represented by the large audience. The Symposium clearly demonstrated the position already reached by aluminium in this field, and indicated a number of possibilities for the future. Its particular purpose, however, was to obtain the views of all concerned in the manufacture and use of packages, so as to highlight problems for aluminium to which research could usefully be directed. That this objective was achieved will be clear from a study of the discussion, which shows quite clearly that aluminium will only progress in its invasion of the packaging field in those applications where it can be proved to have advantages over other materials. There is little doubt that this challenge will be squarely faced by an industry which, particularly since the war, has made such tremendous strides.

The concluding speaker at the afternoon session said he regarded the papers as classics on the subject and looked forward to receiving them in their final form, as they would prove most useful ; with the introduction of coloured illustrations for the first time, they are also most handsomely presented.

Trade Publications

BIRLEC Publication No. 705, recently issued by the Dryer and Gas Plant Division of Birlec, Ltd., gives details of the newly developed range of Birlec nitrogen generators. Particular attention is drawn to the super purity grade which is used in the electronic industry, and to the nitrogen mixtures employed in the metallurgical industries containing proportions of hydrogen or carbon monoxide with hydrogen. These generators separate nitrogen from air by the combustion of fuel, removing carbon dioxide and water by absorption and condensation respectively. Specially designed purification trains are available for eliminating unwanted gases down to low level. Typical running cost analyses are quoted.

THE advantages of colour prints over colour transparencies for many purposes is widely recognised, and with the introduction by Kodak of Type C paper, industrial photographers can now produce excellent colour prints from their own darkrooms with only a few relatively inexpensive additions to the equipment used for black-and-white processing. A leaflet has recently been issued dealing with both the paper and the equipment necessary for processing.

SILICON nitride—a new refractory compound with good mechanical properties at high temperatures, in addition to excellent resistance to corrosion and oxidation, and immunity to attack from many molten non-ferrous alloys—forms the subject of an article in the first issue of *Alloys and Metals Review*, which is to be published on a regular basis by the Alloys Division of Union Carbide, Ltd. Other items are concerned with the scope and achievement of modern stainless steel casting pro-

cesses; briquettes for cupola additions; exothermic ferro alloy ladle additions for alloy steel production by the basic open hearth process; and a new plant for making ferro alloy briquettes and foundry grade alloys.

THE March issue of *The English Electric Journal* contains an article dealing with the automatic controls provided for the Brinsworth hot strip mill of Steel, Peech and Tozer, and illustrates the use of modern control techniques to obtain greater and more economical production in the steel industry. A further article discusses industrial television and reference is made to examples of its use in the steel industry, which to date has been the most active private industry in experimenting with television.

THE efficient treatment of quenching oil has for a long time been a problem in the heat treatment of metals. Circulation of the oil through a suitable cooler keeps the temperature down, thus reducing the tendency to form vapour bubbles, with consequent loss of quenching efficiency, and reduces the liability to excessive oxidation. The problem of cooling quenching oil is discussed in a new brochure, No. 591, issued recently by The Visco Engineering Co., Ltd., which features the Visco Spray-blast cooler, the first oil cooler to use a mixture of air and water as the cooling medium, instead of air only or water only, as had been the previous practice. The system incorporates the advantages of both, without their disadvantages. These coolers can, of course, also be used for cooling transformer oil, etc.

WE have received from the Morgan Crucible Co., Ltd., four new publications dealing with the company's products. One of these, No. F.D. 30, is concerned with the Type E.D.F. Mk. II Birlec-Morgan electric die casting furnace. This is an electrically heated crucible furnace fitted with equipment for temperature control and automatic starting in the early morning. A new oil-fired melting furnace—the Type B.T. Mk. II basin tilting furnace—is featured in F.D. 33. This unit has been designed for rapid bulk melting for both die casting and general non-ferrous foundries. The remaining publications—S.D. 65 and Z.D. 29—deal with Morganite unit type seals and Morganite carbon brushes, respectively.

THE seventh in a series of leaflets dealing with I.C.I. titanium for chemical plant features the use of this metal for compressor valve plates and springs. The advantages of using plate type valves for compressors handling gas or air in bulk have long been recognised, and titanium alloy, with high strength to weight ratio and excellent corrosion resistance, is suitable for valve plates and springs in a much wider range of operating conditions than has been practicable hitherto. It is claimed that the higher cost is more than compensated for by the increased service life.

DETAILS of the box-type furnaces made by Royce Electric Furnaces, Ltd., are given in a new publication of that company. These are made in two ranges—the R.B.M. type suitable for heat treatment at temperatures up to 1,000° C., and the R.B.H. type with a maximum temperature of 1,250° C. The hearth plate of the former is in cast nickel-chromium alloy and of the latter in silicon carbide, the respective heating elements being in nickel-chromium alloy and a special high temperature alloy. Particulars are also given of the inexpensive R.B. type furnaces, suitable for heat treatment or laboratory work in the same two temperature ranges. Illustrations are also shown of furnaces designed to suit individual reuirements.

A NEW illustrated brochure, Publication No. 76, issued by W. C. Holmes & Co., Ltd., bears the title "Holmes-Western 55 Gas Valves." Besides dealing comprehensively with the five main groups comprising the 55 range, the booklet contains a section devoted to the earlier types of Western valves. A "double-page spread" illustrates some thirty valve types—many of them standard—and reference is made to automatically controlled valves and to valve interlocks.

WE have received from the Zinc Development Association copies of two new issues of Z.D.A. publications, the European Zinc Alloy Die Casting Bulletin No. 6 and Die Casting News No. 2 Both these publications describe and illustrate the applications in a wide range of products of zinc die castings which range from small, decorative parts to heavy engineering components. The publications will be particularly useful to designers and production engineers, since they highlight the advantages that zinc alloy die casting has to offer over other methods of manufacture. Copies are available free on request from Zinc Development Association, 34 Berkeley Square, London W.1.

Books Received

"Dendritic Crystallization". By D. D. Saratovkin. 2nd Edition. Translated from Russian by J. E. S. Bradley. 126 pp. New York and London, 1959. Consultants Bureau Inc., and Chapman & Hall, Ltd. $6·00 or 50s. net.

"Growth of Crystal". Reports at the First Conference on Crystal Growth, March 5–10, 1956. Edited by A. Shubnikov and N. N. Sheftal. Original Russian Text Published by Academy of Sciences U.S.S.R. Press, Moscow, 1957. 294 pp. New York and London, 1959. Consultants Bureau Inc., and Chapman & Hall, Ltd. $15·00 or 120s. net.

"Métallurgie de la Soudure". By D. Séférian. Preface by P. Chevenard. 393 pp. inc. author and subject indexes and numerous illustrations. Paris, 1959. Dunod. 5·800 F.

"Elements of Materials Science". By L. H. Van Vlack. 528 pp. inc. index. Massachusetts, 1959. Addison-Welsey Publishing Company, Inc. $8·50. Obtainable in the U.K. from Pergamon Press, Ltd. 64s.

Fifth International Conference on Hot Dip Galvanizing. Edited Proceedings of the Benelux conference held in Holland and Belgium in June 1958. 355 pp. London, 1959. European General Galvanizers Association Secretariat: Zinc Development Association. 60s.

"Non-Destructive Testing." By J. H. Hinsley. Foreword by E. Gregory. 495 pp. inc. subject and name indexes. London, 1959. Macdonald and Evans, Ltd. 75s.

"British Instruments' Directory and Buyers Guide 1959." 322 pp. London, 1959. Scientific Instrument Manufacturers' Association and United Science Press, Ltd. 42s.

"The Manufacture of Iron and Steel." Vol. II. Steel Production. By G. R. Bashforth. Second edition revised. 390 pp. inc. index and numerous illustrations. London, 1959. Chapman and Hall, Ltd. 40s. net.

LABORATORY METHODS

MECHANICAL · CHEMICAL · PHYSICAL · METALLOGRAPHIC

INSTRUMENTS AND MATERIALS

AUGUST, 1959. Vol. LX, No. 358

The Practical Realisation of the HV and HR Scales of Hardness

By R. S. Marriner

(*Communication from the National Physical Laboratory*)

Experiments with precise indentation hardness testing machines are described in which the conditions of loading the indentor are varied and the resulting variations in the hardness values obtained are discussed. Evidence of the necessity for precise control of the loading conditions in standardisation work is given, together with the definition and accuracy of the HV scale of hardness provided by the National Physical Laboratory.

THE definitions of both the diamond pyramid (HV) and Rockwell (HRC and HRB) indentation hardness tests are simple to enunciate, but when their practical interpretation is attempted, using hardness testing machines which purport to load the diamond or ball indentor in the prescribed manner, it is found that machines, even of the same design, can give appreciably different hardness values for the same test specimen. It is therefore traditional practice in the industrial measurement of hardness to verify the machines used by means of standard test blocks. The onus of realizing the definitions in precise practical form thus falls on the limited number of manufacturers and standardizing laboratories throughout the world which accept responsibility for calibrating the standard test blocks.

Of necessity, the standards of hardness provided by each of these authorities are vested in the particular machines which they use, and it has become increasingly apparent, particularly in the Rockwell C scale, that the scales of hardness given by these machines are not in sufficiently good agreement to satisfy present industrial needs. As one of the responsible standardizing laboratories, the National Physical Laboratory has been studying the problems involved with the object of establishing impeccable standards for the HV and HRC scales.

Initially, primary attention was given to the Rockwell scale, where the major lack of agreement exists. Experimental investigation of the influence of the diamond indentor[1] revealed the substantial errors introduced by quite small departures from the postulated form.[2] During this investigation, which was made by means of a deadweight Rockwell type machine built at the Laboratory abour fourteen years ago, it became evident that it would be necessary to design and build a new deadweight machine incorporating modern techniques and having the necessary facilities for the fullest possible control of the indenting procedure. This machine would then constitute the Laboratory's standard for measurements of hardness in terms of the Rockwell C and B scales.

The design evolved for the new machine included a number of novel features which it seemed wise to test experimentally beforehand. Since these features were common to the simpler Vickers type deadweight machine which it was also planned to build, it was decided to proceed first with the construction of the Vickers machine: a description of this machine has been published.[3] The design proved eminently satisfactory, and has therefore been accepted for the deadweight Rockwell type machine which is now in course of construction.

Evaluation of the precision of a standard hardness testing machine is seriously hindered by lack of uniformity of hardness in the test blocks used, since it is impossible to distinguish variability due to the block from variability due to the machine. All commercially available hardness test blocks—and they were sought throughout the world—showed a lack of uniformity which seriously impeded progress, and it became necessary to develop at the Laboratory techniques which would provide test blocks sufficiently uniform in hardness to ensure a reliable basis for the experimental work envisaged. The new deadweight Vickers machine was of great value in this work, which made it possible to produce blocks covering the range 950 HV to 200 HV with a uniformity of hardness to within 1% of their hardness value at the hard end of the range, and within 2% at the soft end. A description of the techniques evolved is being prepared for publication.

With the aid of these uniform blocks it became practicable to investigate precisely, and in detail, the performance of the deadweight Vickers machine. Such effects as misalignment of the indentor, imperfections in its form, and error in the load applied, have been examined. In particular, measurements have been made to determine the influence on the hardness measurement of speed and duration of loading. The results of some of the experiments made with this new machine and with an experimental Rockwell machine, together with the conclusions that the Laboratory has reached in regard to

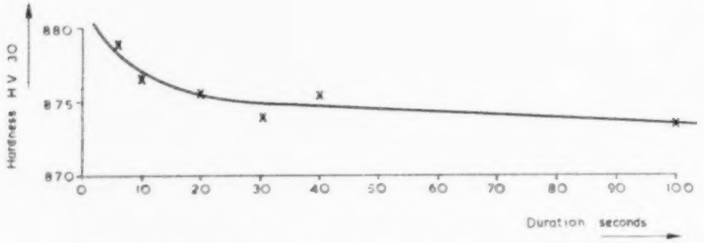


Fig. 1. Change in hardness value with duration of full load.

the definitions and accuracy of the standards of hardness which it will maintain, are the subject of this article.

Misalignment of the Indentor

An important design feature of the new Vickers machine is the free suspension of the load on the indentor, which ensures that there is no loss of load due to friction from guides.[3] The lack of guides necessitates careful balancing of the load so that the indentor does not become inclined to its direction of movement during the penetration of the specimen, and thus deform the indentation. An inclination effect of this kind can occur in conventional type testing machines if the plunger which carries the indentor moves in guides which are not straight, or if clearances are too large and the indentor becomes inclined as the load is applied.

An experiment was made in which the balance of the 30 kgf. load was disturbed by different amounts, and thus the inclination of the indentor during penetration was varied. It was found that a change of inclination of 10 seconds of arc was necessary before a change of hardness value of 3 HV could be detected on a test block of hardness 900 HV. As the balance of the loads on this machine can be set easily to give repetition within 2 seconds of arc, it was concluded that errors from this source would be negligible.

Because of the lack of guides, out-of-balance forces can rotate the load and indentor about the indentor's axis during penetration, and care was taken in the design and manufacture to ensure that rotation during penetration would be negligible. To investigate the effect of rotation of the indentor, groups of indentations were made in which the indentor was deliberately rotated by increasing amounts. It was found that to produce a detectable change in hardness value, the rotation had to be sufficient to produce obvious rounding of the corners when the indentation was viewed in the measuring microscope. It was concluded from this experiment that, provided the corners of an indentation appear sharp, then no appreciable error can have been introduced due to rotation of the indentor.

Error in Load

To determine practically the magnitude of errors in hardness value due to errors in load, groups of ten indentations were made on a test block with small additional loads attached to the standard load of 30 kgf. The loads used and the mean size of the diagonals of the groups of ten indentations are given in Table I. Col. 3 of the table gives the hardness values for the block as calculated from the known loads and the mean measured diagonals, whilst Col. 4 shows the hardness values determined from the mean measured diagonals and an assumed constant load of 30 kgf. Finally, the expected values for the mean diagonals computed from the mean hardness value and the known loads are shown in Col. 5.

TABLE I.—HARDNESS VALUE AND ERROR IN LOAD

Col. 1.	Col. 2	Col. 3	Col 4	Col. 5
Load (P) (kgf.)	Mean Diag. (d) (μm.)	$HV = \frac{2P \sin\theta/2}{d^2}$ (HV)	$HV = \frac{2 \times 30 \times \sin\theta/2}{d^2}$ (HV)	$d = \left(\frac{2P\sin\theta/2}{880 \cdot 2}\right)^{\frac{1}{2}}$ (μm.)
30·00	251·4	880·2	880·2	251·4
30·30	252·6	880·6	871·9	252·7
30·60	254·0	879·5	862·3	253·9
31·50	257·6	880·3	838·4	257·6

The following deductions may be drawn from Table I :—

(1) The hardness values obtained for the block (Col. 3) are in remarkable agreement over the range of loads used. This agreement not only demonstrates that, for heavy loads, the hardness value is independent of the load used, but also indicates the precision of this indentation hardness test and the reliability of the mean of ten indentations on a test block whose total variability is about 12 HV.

(2) Col. 4 shows that, for this standard load and level of hardness, an error of 35 gf. in the load introduces an error of 1 HV in the hardness value obtained. In round figures, 0·1% error in load is equivalent to 1 HV at this level and is the maximum load error which should be permitted in good industrial machines.

(3) Col. 5 shows the expected values for the mean diagonals, and these depart from the observed values by only 0·1μm. This agreement demonstrates the accuracy that can be attained in indentation hardness testing, and is typical of the accuracy that has been obtained in a number of experiments with the apparatus at the Laboratory.

Duration of Full Load

Ancillary pneumatic equipment in the standard indenting machine indicates precisely the moment when the full load is applied to or removed from the specimen, and the design of the machine permits the duration of the full load to be varied independently of all other conditions of test.[3] To determine the effect of the duration of the full load upon the hardness value obtained, experiments were carried out in which groups of ten indentations were made on a test block under identical conditions of test, except that the duration of the full load was changed for each group of indentations.

The results obtained for two test blocks of hardness 875 HV and 220 HV are shown in Figs. 1 and 2 where the mean hardness value obtained for each group of ten indentations is plotted against the duration of the full load. It will be seen that for the harder test block (Fig. 1), the curve rises appreciably for durations less than 20 seconds, but for durations between 30 and 100 seconds, although static equilibrium may not have been attained, the change of hardness value is in the neighbourhood of

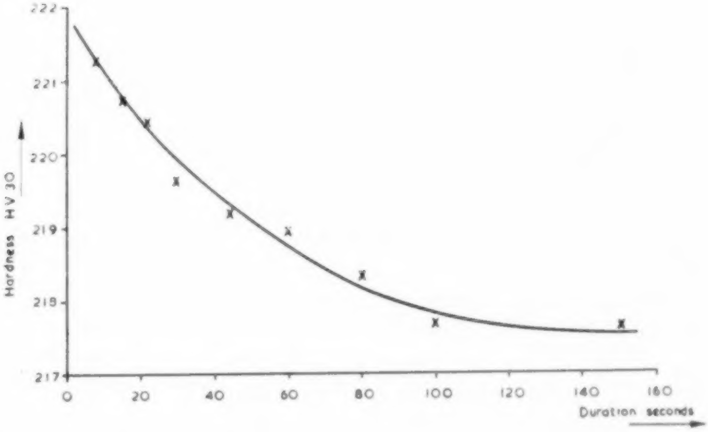


Fig. 2.—Change in hardness value with duration of full load

only 1 HV. Such results indicate that for hard specimens the minimum duration for the full load should be 30 seconds. However, Fig. 2 shows that for a soft test block, static equilibrium is not achieved for at least 2 minutes after the application of the full load. Even for calibration work this is an excessively long time to maintain the full load, from both an economic point of view and the difficulty of ensuring complete freedom from external vibration.

These results are in agreement with the readily acceptable fact that the time required to achieve static equilibrium after the full load is applied is proportional to the load used and inversely proportional to the hardness of the test specimen. It may therefore be expected that the effect will be even greater in the Rockwell C test, where the full load is 150 kgf., and users of this test are aware of the considerable creep of the indicator when the full load is applied to soft specimens.

It will be apparent from these results that agreement between the different standardizing authorities will not be reached unless the definitions of the indentation hardness tests specify precise limits for the duration of the full load.

Speed of Loading

A prime consideration in the design of industrial indentation hardness testing machines is that the hardness test shall be carried out in a minimum of time, but without undue loss of accuracy. To achieve a short cycle of operation without introducing impulsive forces, the loading mechanism is usually designed so that the rate of penetration of the indentor is high in the initial stages, but diminishes to near zero values as the resistance to penetration increases and the indentation is nearly completed. In the majority of machines there is a final stage in the indenting process which occurs when the load controlling mechanism becomes clear of the load before the resistance to penetration is equal to the full load. In such machines the full load is applied a little before the indentation is completed, and penetration continues at a diminishing rate until static equilibrium is achieved or the load is removed.

That such a stage must exist is revealed by Fig. 2. A machine which has a complete cycle of operation of, say, 20 seconds, and is also designed so that the load controlling mechanism becomes clear of the load during this cycle, must transfer the full load to the specimen before penetration is complete if the characteristics of the specimen will not permit the attainment of static equilibrium within 20 seconds. The important consequence of this final stage of the indenting process is that the full load is transferred to the test block at a finite velocity, and the hardness value obtained is dependent on this velocity.

As rapid hardness testing was not a prime requisite for the Laboratory's standard machine, it was designed so that the load could be applied at a uniform velocity whilst under control of the load applying mechanism. This velocity can be controlled within very close limits and can be varied from one hundred-thousandth of an inch per second to several thousandths of an inch per second. The load controlling mechanism is in the form of a horizontal surface which carries the deadweight load and moves downwards at a constant velocity. This arrangement ensures a uniform rate of penetration until such time as the test block refuses to accept the load at the pre-set constant velocity. At this moment the surface breaks contact with the load and the full load is transferred to the indentor, which continues to penetrate the test block at a diminishing rate until either static equilibrium is achieved or the motion of the horizontal surface is reversed so as to pick up the load at the end of the specified duration period.

A number of experiments were made in which groups of ten indentations were made on a test block under identical conditions, except that the uniform velocity of loading was changed for each group of indentations. Typical results obtained on two test blocks of hardness 950 HV and 500 HV are shown in Figs. 3 and 4, where the mean hardness value obtained for each group of ten indentations is plotted against the velocity of penetration. It will be seen from these results that as the velocity of penetration is decreased the hardness value increases, and in particular the rate of increase is greatest as near-zero velocities are attained. This asymptotic approach of the curve to the vertical axis was found to be typical of all the velocity-hardness curves obtained, and shows that, when slow rates of penetration are used, the hardness values obtained will show large variations if the rate of penetration is not controlled within very close limits.

It was impracticable to obtain hardness values for velocities below 0·00001 in./sec., due to the difficulty

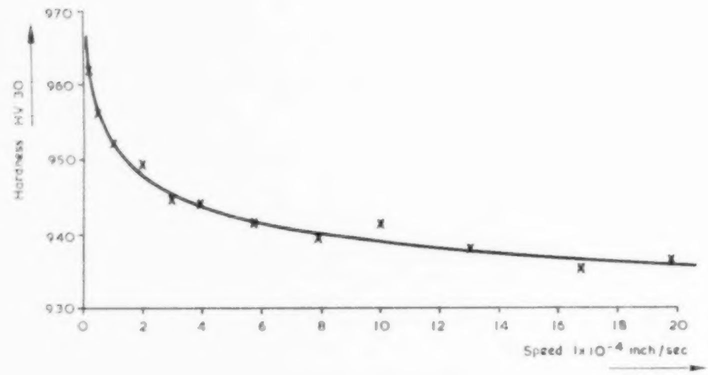


Fig. 3.—Change in hardness value with speed of loading.

of measuring the velocity. However, an attempt was made to simulate the conditions that would obtain at extremely slow velocities by setting the rate of loading to 0·00005 in./sec., and then stopping the descent of the load for a few seconds at the moment when the pneumatic indicator showed that contact between the load and the controlling mechanism was at the point of breaking. After the few seconds pause, the controlling mechanism was lowered clear of the load and the full load maintained for 30 seconds. It is doubtful whether this technique would bring the load completely to rest, as the surface on which the load rests is hydraulically controlled and creeps very slowly when not being driven. To ensure that the load had been truly brought to rest, the experiment was repeated, with the exception that the movement of the controlling surface was momentarily reversed when the pneumatic indicator showed that contact was about to break, and the surface was then brought clear of the load. A number of indentations were made on a hard test block under these two conditions. The mean hardness values obtained, together with the mean hardness values for this test block at other velocities, are given in Table II.

Although the velocities of loading for the last two values in Table II cannot be stated, the hardness values obtained confirm that the velocity-hardness curve approaches the axis asymptotically, and the table demonstrates the large range of hardness values which can be obtained merely by changing the velocity of loading.

To determine which stage of the penetration is the most important, advantage was taken of the fact that the design of the indenting machine permits rapid changes of the velocity of loading to be made during the period of penetration. Experiments were carried out in which the velocity of penetration was changed from a high rate during the first part of the indentation to a low rate before the full load was transferred, and vice-versa. It was found in each experiment that it was the final velocity which determined the size of the indentation, and hence the hardness value obtained. This result applied whether the velocity was changed early or late in the period of penetration, and even applied in the experiments where the load was arrested at the moment of transfer, i.e. if the load were arrested at the moment of transfer, the hardness value obtained was independent of the initial rate of penetration.

TABLE II.—MEAN HARDNESS VALUE OBTAINED AT DIFFERENT VELOCITIES OF LOADING

Velocity of Loading (in./sec.)	Mean Hardness Value (HV)
0·00166	866
0·00060	874
0·00034	877
0·00012	881
0·00002	890
Controlling surface stopped	895
Controlling surface reversed momentarily	907

Although this 'velocity of loading' effect is serious in the diamond pyramid hardness test, it does not present insurmountable difficulties in the maintenance of common standards of hardness by standardizing authorities, nor does it seriously affect the verification of industrial machines. On the contrary, an awareness of this effect should make it possible to eliminate some of the performance differences which exist between industrial machines.

Because of the greater loads used in the Rockwell C test, it was thought advisable to investigate this velocity of loading effect in the Rockwell test as it might be necessary to control the rates of penetration of the standard machine to be built within closer limits than had been envisaged. An experimental Rockwell machine was therefore made in which the 10 kgf. minor load and 140 kgf. major load could be independently controlled to vary the rate of penetration as each was applied.

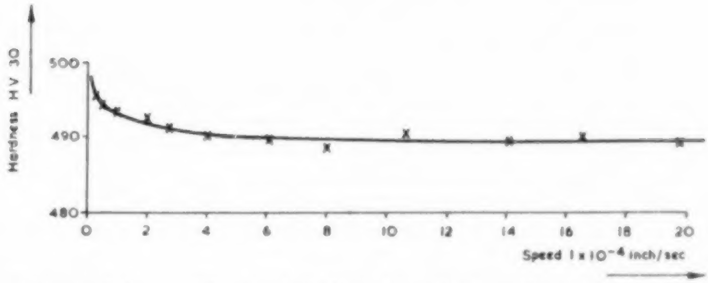
The results of experiments with this machine showed that the hardness value obtained was affected by the rate of penetration for both minor and major loads, but that the effect was greater for changes in velocity of the major load. The effect of changing the rate of application of the major load on a test block of hardness in the neighbourhood of HRC 68 is shown in Fig. 5. It will be seen that a change of hardness value of HRC 1 can be obtained for a change of velocity of 0·00015 in./sec., and it is evident from these results that the standard Rockwell machine must be designed to control the rate of penetration within close limits if variation in hardness value from this source is to be eliminated.

Indentors

Examination of diamond pyramid indentors from a number of suppliers has shown that indentors with flat pyramidal faces, included angles within ±5 minutes of arc of the nominal 136°, and points which are free from a ridge longer than 0·00002 in. are readily obtainable.

Performance tests with indentors of this quality on hard test blocks have shown that a variation of hardness value of 2 HV is the most that should be encountered. With imperfect indentors, an error of 30 minutes of arc has been shown to introduce an error of 7 HV on a test

Fig. 4.—Change in hardness value with speed of loading.



block of hardness 940 HV, whilst indentors whose points have become slightly rounded have been shown to give values which are too large by about 5 HV.

The variation in hardness value in the Rockwell C test which can be introduced by the indentor is known to be large,[1] and a thorough investigation of this source of error will be undertaken when the new standard Rockwell machine has been built.

Conclusions

It is evident from the results of the experiments discussed above, and from a general consideration of indentation hardness testing, that the hardness value obtained from a single indentation may be expressed as the sum of

(1) the average hardness of the test block ;

(2) a contribution due to the local area indented having a structure which is not average ;

(3) a contribution from the indentor which may give values which are consistently higher or lower than that given by an average indentor ;

(4) a constant contribution from the indenting machine due to such factors as incorrect load ;

(5) a variable contribution from the indenting machine due to friction, misalignment of the indentor, external vibration, etc.

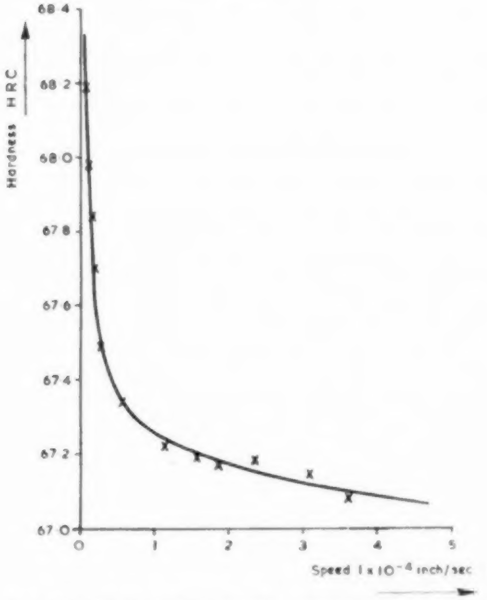


Fig. 5.—Change in hardness value with speed of application of major load (Rockwell).

(6) a contribution dependent on the rate of loading ;

(7) a contribution dependent on the duration of the full load ;

(8) a contribution which may be random or systematic due to the measuring device and observer ; and

(9) a contribution due to sources of variability not listed above.

These contributions may be classified under three headings, and for any particular standard machine, which in the case of the diamond pyramid hardness test comprises an indenting machine and a measuring microscope, they are as follows

(*a*) constant effects arising from the design of the machine (3, 4, 8) ;

(*b*) effects which can be made constant by suitable control of the machine (6, 7) ; and

(*c*) random effects (2, 5, 8, 9).

By attention to design and the choice of uniformly hard test blocks, a standardizing authority may reduce the contributions from (*a*) and (*c*) to a minimum, and can arbitrarily fix the contributions from (*b*) so that a scale of hardness can be maintained which is constant within close limits. However, it should be noted that this scale is not an absolute scale of hardness, but is vested in the particular indenting machine and measuring microscope regarded as the standard.

The standard indenting machine built by the National Physical Laboratory has been designed so that the constant errors referred to above are not only small, but are unlikely to change with time because the moving components of the machine, which are subject to wear, cannot influence the hardness values obtained. Similarly, the performance of the measuring microscope is standardised by means of a line standard which can be kept constant regardless of time. However, the scale of hardness given by this machine can be arbitrarily shifted, by amounts which are commensurate with the tolerances used in industry, by changing the rate of loading and the duration of the full load.

To obtain consistent results from hardness tests carried out at the National Physical Laboratory, it has been decided to fix these variables provisionally at 0·0003 in./sec. for the final rate of loading, and 30 seconds for the duration of the full load.

The choice of these particular values has been determined by the following considerations :—

(*a*) both rate of loading and duration of full load can be easily controlled at these values ;

(*b*) small departures from these values do not appreciably affect the hardness values obtained at any level of hardness ;

(*c*) the size of the indentations made by the standard

machine working at these values is not far removed from the size of indentations produced by currently accepted industrial machines working with loads in the range 30–120 kgf.; and

(*d*) the time taken to standardize a test block when using the standard machine at these rates is economically acceptable.

The accuracy with which the hardness of test blocks as uniform as those produced by the N.P.L. can be determined from the mean of ten indentations when using the standard machine under controlled conditions, is indicated by the close fit of the observed values to smooth curves in Figs. 1–4. These results, together with repeated observations on test blocks over the past two years, indicate that the Laboratory is maintaining a constant diamond pyramid scale of hardness and that, in terms of this scale, the hardness of a test block which is free from large variations can be determined from the mean of ten indentations to an accuracy of $\pm 0 \cdot 5\%$ of the mean hardness.

Acknowledgments

The author desires to acknowledge the assistance of Mrs. J. G. Wood of the Standards Division, N.P.L. and Mr. Koza Iizuka of The Central Inspection Institute of Weights and Measures, Tokyo, who carried out much of the experimental work described in this paper. The author also wishes to acknowledge the advice and assistance of Dr. J. C. Evans, who is responsible for the work of the Engineering Section of the Standards Division.

The work described above has been carried out as part of the research programme of the National Physical Laboratory, and this paper is published by permission of the Director of the Laboratory.

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BISRA Open Days

THE British Iron and Steel Research Association is planning two Open Days at the laboratories at Battersea Park Road, London, S.W.1, on Thursday and Friday, October 22nd and 23rd. The Open Days will provide an opportunity for showing the current and continuing work of BISRA'S London Group Laboratories, which, besides the Battersea premises, include part of the Ironmaking Division housed at the Imperial College of Science at South Kensington. The Battersea premises house the laboratories of the Association's Plant Engineering and Energy Division, and the Departments of Physics, Chemistry and Operational Research.

In the Plant Engineering and Energy Division's laboratories, the Electrical Engineering Section will display the extensive work being done on electrical control and recording ; this will include, for example, the Tallimarker apparatus, one of the latest developments in information handling. The Civil Engineering Section will be showing work on the design and testing of girder and gantry structures, whilst the Mechanical Engineering Section will have on display a number of projects relating to the handling of bulk materials, and hydraulic and other control systems for steelworks' plant. The recently formed Energy Section of the Division will mount displays relating to its recent inquiry into the fuel consumption of the industry.

In the Physics Department, the new Automation Section will be showing one of its first projects, involving the automatic deseaming of billets. The Instrument Section will highlight several projects in support of the premise that instruments are the first step towards automation, while the Metal Physics Section will show something of the continuing investigations into the problem of combined creep and fatigue. The Chemistry Department will be highlighting the work of its Physical Chemistry, Corrosion and Refractories Sections. The latter will be showing a development in open-hearth furnace roof design which has already shown in production tests to offer a much longer working life than conventional designs.

The Operational Research Department, besides showing the work of its Computer Application Section and Human Factors Section (which latter includes ergonomics) proposes to highlight the work of its Operational Investigation Section, which has already carried out studies on behalf of a number of firms throughout the industry. A special display of one of the most important projects of BISRA's Ironmaking Division is being prepared, to illustrate the principle of the recently-developed SCICE (Stationary Charge In Controlled Environment) apparatus.

The Open Days will also give visitors the opportunity of seeing the considerable structural alterations which have taken place in the old complex of buildings at Battersea. This is the first step in a long-term plan for the complete rebuilding of the premises, which in their long history have served as a laundry, tramcar depot, and research centre.

Formal invitations to the Open Days will be issued to BISRA member firms very shortly. A general invitation is, however, extended to all industrialists and others interested in the engineering and technical problems which concern the iron and steel industry. The Information Officer of BISRA at 11, Park Lane, London, W.1 will be glad to hear from those wishing to attend.

Inco Research Fellowship

THE INTERNATIONAL NICKEL CO. OF CANADA, LTD. and The Canada Council—a body established by the Canadian Government for the encouragement of the arts, humanities and social sciences—have announced the establishment of a fellowship to honour the recent visit of the Queen and the Duke of Edinburgh to the nickel mines in the Sudbury area. By gracious permission of Her Majesty, the fellowship being established will be called "The Queen Elizabeth II Fellowship (The International Nickel Company of Canada, Limited, Royal Tour, 1959)". The award will be a post-doctoral fellowship, tenable for two years, under the terms of which research may be undertaken in the chemistry or physics of metals, geophysics, geology, metallurgy, mineralogy, or mining. Candidates must be Canadian citizens and holders of a doctor's degree, and the fellowship must be held at a Canadian university. Inco has deposited a total of 15,000 dollars with the Canada Council and the Council will supervise all arrangements for the fellowship.

The Analysis of Nickel

Part I—Chemical Methods

By T. R. Andrew and C. H. R. Gentry

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A critical survey is given of published methods for the chemical determination of the alloying constituents and impurities in electronic nickel. On the basis of a re-examination of the published methods and additional investigations, specific methods for each element have been formulated. Detailed instructions are provided for carrying out the several methods with statements of the time required and the precision attainable under routine conditions. Several of the methods, which are mainly photometric, are original, and all should be applicable to other non-ferrous metals in addition to nickel.

(*continued from page* 30 *of the July issue*)

Cobalt

In view of the close association of cobalt and nickel, it is not surprising that a wide variety of procedures has been put forward for the determination of cobalt in nickel. The oldest method still in use is the potassium cobaltinitrite procedure of Fischer,[21] which has been used by Kallmann[22] and modified by Salyer and Sweet[23] who incorporated isotope dilution.

Consequent upon the introduction of 1-nitroso-2-naphthol by Ilinsky and von Knorre[24] most gravimetric methods used this reagent and, after a zinc oxide separation, this still remains the procedure advocated by Inco[1] and A.S.T.M.[2] for general nickel analysis. Two other gravimetric methods have recently been proposed by Ponomarev[25] and by Saltikova,[26] but these, weighing as cobalt zinc mercuric thiocyanate or silver cobalticyanide, would appear to offer no great advantages over the other gravimetric techniques, and to suffer from the same limitations in requiring a large sample weight.

The volumetric determination of cobalt by titration with ferricyanide is well established, and its application to nickel analysis has been studied by Hall and Young.[27] Electronic nickel, however, often contains too little cobalt to permit the simple use of this procedure. Similar objections can be raised against the polarographic technique of Watters and Kolthoff[28] which, in the authors' hands, has not proved applicable to cobalt contents below 0·05%.

Smales, Mapper and Wood[29] have put forward an elegant radio-activation method for the determination of traces of cobalt in steel. This method should be equally applicable to nickel, but requires access to an atomic pile or other source of high neutron flux, and is consequently not suitable for rapid analytical control in a works laboratory.

Having rejected all these methods for one reason or another, a close scrutiny and examination was made of the myriad photometric procedures which have been described in the past twenty years. Two of the newer reagents appeared to be most promising—3-methoxy-5-nitrosophenol, proposed by Torii[30] and independently by Peach[31]—and diacetylmonoxime *p*-nitrophenylhydrazone suggested by Feigl and Goldstein.[32] Attempts to utilise the procedure of Feigl were unsuccessful, but work on the method of Torii gave promising results. This work was finally abandoned because of the difficulty of preparing the reagent in any reasonable quantity.

The use of nitroso-R salt as advocated by A.S.T.M.[2,3] is, in our opinion based on work on steels, unsatisfactory for low levels of cobalt, since large amounts of reagent must be added to combine with the nickel, giving rise to a high optical density even in the absence of cobalt. This procedure has been studied by Claassen and Westerveld[33] and by Finkelshtein,[34] who advocates preliminary separation of nickel and copper. Dean[35] has an interesting variant in which he carries out a chromatographic separation after formation of the cobalt nitroso-R salt complex.

Middleton and Stuckey[36] have applied chromatographic separation to the photometric determination of cobalt with 1-nitroso-2-naphthol after prior purification of the reagent. Claassen and Daamen[37] have proposed 2-nitroso-1-naphthol for the photometric determination of cobalt in nickel, and in our experience this procedure gives excellent results, but suffers from two minor disadvantages—the need to purify the reagent, and the need to maintain the *p*H within the rather close range 3·0–3·8. Nitrososalicylic acid has been suggested as a reagent by Perry and Serfass,[38] but requires the absence of copper.

The blue colour given by cobalt thiocyanate in the presence of organic solvents such as acetone has been known for almost a century, and has been studied by Young and Hall[39] and by Uri.[40] Both these workers state that the calibration curve is non-linear, and the values adduced indicated that the sensitivity of the procedure is inadequate for the analysis of electronic nickel. However, it has been shown by Dwyer, Gibson and Nyholm,[41] and subsequently by Affsprung, Barnes and Potratz,[42] that tetraphenylarsonium chloride reacts with cobaltous thiocyanate to give a product which may be extracted from aqueous solutions by chloroform to give an intense blue solvent layer. Recent work by Zeigler and Glemser[43] suggests that a similar reaction takes place with tri-*n*-butylamine, but this has not been studied by the authors.

The advantages of the tetraphenylarsonium cobaltothiocyanate procedure are that it gives a linear calibration curve of adequate sensitivity; is rapid and simple to operate; has a usable *p*H range of 2–7, permitting considerable latitude in operation; and is subject to interference, in the case of electronic nickel, only from

ferric iron, an interference which may readily be eliminated by the addition of ammonium fluoride or fluoborate.

The method finally devised is as follows :—

Dissolve 100 mg. sample in 2 ml. nitric acid (1 : 1) and evaporate to dryness on a steam bath. Add 2 ml. hydrochloric acid and repeat the evaporation to dryness in order to remove the majority of the nitric acid. Dissolve the residue in about 10 ml. water and transfer to a separating funnel of 100 ml. capacity. Add ammonium hydroxide solution (1 : 1) until the deep blue nickel ammine is formed, and add hydrochloric acid (1 : 1) dropwise until this colour is destroyed. Dilute to approximately 25 ml. and add 5 ml. 50% ammonium thiocyanate solution. Mix and add 10 ml. 1% ammonium fluoride solution followed by 10 ml. 0·1% tetraphenylarsonium chloride solution. Mix well and allow to stand for ½–1 minute. Add 10 ml. chloroform and shake vigorously for 1 minute. Allow the layers to separate, and run off the lower layer into a clean dry 25 ml. graduated flask. To the solution left in the separating funnel add a further 5 ml. 0·1% tetraphenylarsonium chloride solution, allow to stand ½–1 minute and repeat the extraction with 10 ml. chloroform. Combine the extracts and dilute to 25 ml. with chloroform.

Transfer the chloroform solution to a clean dry 50 ml. beaker containing approximately 1g. anhydrous sodium sulphate and mix gently. Decant the clear liquid into a photometer cell and measure the optical density. Suitable conditions are : (*a*) using filament lamp, H503 and Ilford 607 filters—1 cm. cell, 0–1·2% Co ; 4 cm. cell, 0–0·3% Co ; (*b*) using spectrophotometer at 620 mμ—1 cm. cell, 0–1·0% Co ; 4 cm. cell, 0–0·25% Co.

By reducing the volume of chloroform used for extraction, analyses may be made on sample weights as low as 10 mg., provided that micro-absorption cells are used.

It has been the authors' experience, using AnalaR reagents, that no cobalt is picked up in the procedure, and there is no need, therefore, to carry through a blank determination. For calibration purposes, it is not necessary to add nickel, provided that the *p*H range is adhered to. The presence of nickel, however, facilitates this adjustment of the *p*H, and it is not necessary that it should be abolutely free from cobalt, since the optical density of the solution to which no cobalt has been added can be subtracted from the values obtained with the synthetic standard solutions. This is permissible, since the reagent solution has negligible absorption at the wavelength chosen for measurement. For preparing the synthetic standard solutions, either pure cobalt or a standardised solution of a cobalt salt may be used ; in both cases the solution must be free of nitrate.

The procedure is very simple in operation and, when analysed in batches, less than twenty minutes is required for each sample. The precision of the method is such that in samples containing up to 0·1% cobalt the average deviation from the mean of a number of replicate determinations on several samples was less than 0·001% cobalt. On the Mond Nickel Company's standards, the coefficient of variation for a single determination was found to be ±2·5%.

Copper

Many methods have been proposed for determining copper in nickel or its salts ; the problem is not to find an adequate method, but to make a choice from those available.

The electrolytic determination of copper after prior separation as the sulphide is advocated by Inco[1] and the A.S.T.M.[2] Although capable of giving excellent results, these procedures require large sample weights and are much more time-consuming than most of the photometric methods which have been put forward.

Photometric methods for the determination of traces of copper in the presence of large amounts of nickel have been based upon the use of the cuprammonium complex,[44] the red-violet colour given by cupric copper in the presence of hydrobromic and phosphoric acids,[3] extraction with dithizone,[45, 46] extraction of the diethyldithiocarbamate in the presence of E.D.T.A.,[47, 48, 49] extraction using cadmium diethyldithiocarbamate,[50] and extraction of the 2-2′ diquinolyl complex.[51] No doubt many other reagents could be used, and in particular very satisfactory methods could probably be based on the specific reagents, 2 : 9-dimethyl-1:10-phenanthroline[52], 2:9-dimethyl-4:7-diphenyl-1:10-phenanthroline,[53] or bis-*cyclo*hexanone oxalyldihydrazone.[54]

Although otherwise satisfactory, the procedure of the A.S.T.M.[3] is, in the present authors' view, too long, involving as it does a preliminary filtration followed by a separation of the copper on to lead before the photometric finish. Of the other published methods, the present authors prefer those based upon the use of the dithiocarbamate or diquinolyl extracts. Several versions of the dithiocarbamate method have given good results, in particular a method[55] due to Claassen and Bastings which uses lead diethyldithiocarbamate. However, since the diquinolyl method[56, 57] has been adopted in this Laboratory since 1952 for the general determination of small amounts of copper, its use has been preferred for the analysis of nickel. It has no apparent disadvantages in comparison with other published methods.

The details of the method as used in this Laboratory are essentially the same as those recommended by the B.I.S.R.A. Physico-Chemical Methods of Analysis Sub-Committee for the determination of copper in steel[58] and adopted as a British Standard.[59] The execution of this method is simpler than that proposed by Elwell.[51] For keeping the hydroxides in solution, the B.I.S.R.A. procedure using citrate has been retained in the interest of standardisation, although some slight advantage might be had by using tartrate instead. In particular, it might be noted that over the *p*H range 2–8 the extraction of the copper complex is effectively complete from tartrate solution with 1 minute's shaking ; in the presence of much citrate, however, this is not so with pure copper solutions, although it is in the presence of large amounts of iron.

The method proposed is as follows :—

Weigh 0·25 g. sample into a 250 ml. beaker. Dissolve in 10 ml. nitric acid (1 : 1) and 10 ml. phosphoric-sulphuric acid (3 : 3 : 14). Take to fumes. Cool, take up in a little water and dilute to 50 ml. in a graduated flask. Pipette 10 ml. into a 100 ml. beaker, add 1g. hydroxylamine hydrochloride and warm on the steam bath for 5 minutes. Cool rapidly to room temperature, add 10 ml. ammonium citrate solution (made by dissolving 40 g. citric acid in 20 ml. water, cautiously adding 50 ml. conc. ammonia and diluting to 100 ml.) and wash with a minimum of water into a 50 ml.

separating funnel. Add from burette 10 ml. 0·05% 2-2′-diquinolyl in amyl alcohol and shake vigorously for 2 minutes. Allow layers to separate and run-off and discard the lower layer. Run-off the alcohol layer into a 1 cm. cell through a dry 9 cm. filter paper (Whatman 540). Measure the optical density against a water cell using either an absorptiometer with a mercury vapour lamp and Wratten 74 with H503 filters, or a spectrophotometer at 545 mμ. Carry out a blank determination on the reagents, preferably using copper-free nickel and apply a suitable correction. The range of the method on the absorptiometer is up to 0·2% copper.

For calibrating the method, a series of synthetic solutions made from pure nickel and a standard solution of copper in nitric acid may be used. If copper-free nickel is not obtainable, an appropriate zero correction must be applied. The present authors have never encountered any difficulties with this method using *iso*amyl alcohol of milk-testing quality and diquinolyl from several sources.

The method is specific for copper ; the phosphoric acid keeps any tungsten in solution and any insoluble silica which is transferred with the aliquot taken is retained in the filter paper used primarily for drying the organic layer. The method is rapid, and batches of samples can be analysed at a rate equivalent to about twenty minutes per determination. When applied to the Mond Nickel Company's standards on a routine basis, a co-efficient of variation for a single determination of ± 6% was found.

Iron

Both Inco[1] and A.S.T.M.[2] advocate a volumetric determination of iron, after preliminary ammonia separation, on a 5–10g. sample of nickel. The A.S.T.M. procedure for electronic nickel[3] uses a photometric thiocyanate procedure without separation, but this does not meet the present requirements since it is not applicable in the presence of tungsten. In this Laboratory, a simple photometric procedure using thiocyanate was also used for many years, but to get results of the highest accuracy it was advisable to carry out a separate calibration with each batch of determinations. This was felt to be unsatisfactory and attention was turned to the development of an alternative procedure.

Ferric iron can readily be extracted into organic solvents, and by taking advantage of this fact a photometric method could obviously be developed. However the requirement was for a simple method and, in view of the large number of methods extant for the photometric determination of iron (see, for example, West[60]) a direct method was considered to be possible. Three such methods have been investigated in detail. These utilised 1:2-dihydroxybenzene-3:5-disulphonic acid (disodium salt)—i.e. tiron, tartaric acid, and nitroso-R salt, respectively.

The authors' early experiments were based on the use of 1:2-dihydroxybenzene-3:5-disulphonic acid (disodium salt), as advocated by Yoe and Jones[61]. This reagent had already been applied to iron determination in nickel by Potter and Armstrong[62] who, however, made a preliminary separation with ammonia. Since it was desirable to avoid this, the authors have studied the possibility of directly determining iron in nickel with this reagent. The difficulties caused by the high optical density of the nickel at the operating wavelength (550 mμ) in a sodium borate buffer were overcome by addition of potassium cyanide after colour formation. This procedure gave good results in the authors' hands, but was abandoned when other associated laboratories reported inconsistent results when using it.

The next procedure to be considered was proposed by Nielsch and Böltz[63] for the determination of iron in copper alloys. This elegant method utilises the absorption of ferric tartrate at 350 mμ in the presence of excess tartaric acid at pH 2·5. A compensating solution is obtained by addition of sodium pyrophosphate to the solution which forms a stronger iron complex than the tartrate.

Using this procedure, excellent, reproducible, linear calibration graphs were obtained on pure nickel solutions to which iron had been added. However, when applied to actual nickel alloys, for some inexplicible reason, the pyrophosphate failed to destroy fully the ferric tartrate complex. Because of this, it was necessary to dispense with the compensating solution and to apply a correction for the absorption due to the nickel. In this way, very good results were obtained, but the procedure was not considered as simple as that of the third technique which was tried.

In 1957, Dean and Lady[64] put forward a method of general applicability for the photometric determination of ferrous iron with nitroso-R salt. In essence, this relied on the reduction of iron to the ferrous state with hydrazine, addition of sufficient nitroso-R salt to react with all the elements present, adjustment of the pH to 6–7, and heating to 90° C. until the interfering complexes and excess reagent were destroyed and the iron colour fully developed.

This procedure works fairly well for nickel, but is open to one or two objections. In particular, the ferrous nitroso-R salt complex is not entirely stable in the presence of hydrazine at elevated temperatures, and it requires some skill to judge the precise moment at which to remove the solution from the steam bath or other source of heat. Destruction of the coloured complexes without destruction of the excess nitroso-R salt is not practicable in this pH range, because of the absorption of the reagent at the wavelength of measurement (720 mμ.).

Reference to the earlier work of Griffing and Mellon,[65] however, showed that at pH values below 5 the transmission of nitroso-R salt solutions was almost 100% at 720 mμ. It was further stated by these authors that the ferrous nitroso-R salt colour could be fully developed in the cold by standing for 20 minutes. On pure iron solutions, this procedure was found to be satisfactory, but it was still necessary to eliminate the interference formed by the nickel and other metal nitroso-R salt complexes. It was found experimentally that all these complexes, other than cobalt, were destroyed by addition of ethylenediaminetetra-acetic acid (disodium salt), (Complexone III). The absorption spectrum of cobalt is sufficiently removed from that of iron[65] to constitute no interference.

Two points should be noted particularly about this procedure. Firstly, since the iron competes for nitroso-R salt with nickel and other complex-forming metals, it is essential that sufficient nitroso-R salt be added to provide a slight excess over all requirements. If insufficient is added, but the amount is precisely controlled and the nickel content is constant, a linear calibration graph is still obtained, but of greatly reduced sensitivity.

Secondly, all British supplies of nitroso-R salt and hydrazine hydrochloride tested by us contain iron and need to be purified. Fortunately the treatment is in both cases very simple. Hydrazine hydrochloride is dissolved in water and filtered from the insoluble impurities. The filtrate is made about 1N with hydrochloric acid and the white crystalline precipitate collected and washed with alcohol. Nitroso-R salt is purified by dissolving in hot water to make an approximately 5% solution and allowing to cool. The clear yellow product is filtered, washed with 50% alcohol followed by ether, and allowed to dry in air.

The final form of the procedure is as follows :—

Dissolve 25 mg. sample (for nickels containing <0·2% Fe) in 1 ml. dilute nitric acid (1 : 1) and add 2 ml. hydrochloric acid. Evaporate to dryness and take up in 10 ml. 1% hydrochloric acid. Filter, if necessary, and transfer to a 100 ml. graduated flask. Add, in this order and mixing between additions, 5 ml. 10% hydrazine hydrochloride, 25 ml. 1% nitroso-R salt and 10 ml. 1M acetic acid–1M ammonium acetate buffer solution. Allow to stand 30 minutes, add 10 ml. 2% ethylenediaminetetra-acetic acid (disodium salt), dilute to the mark, mix, allow to stand 2–3 minutes, and measure the optical density in a 4 cm. cell at 720 mμ. The range of the method is up to 0·2% iron.

A blank determination on iron-free nickel, or on nickel containing a known small amount of iron, should be carried through the procedure to compensate for the small colour blank. A calibration curve is prepared in the same way from iron-free nickel to which standard additions of iron are made.

A batch of six samples may be analysed in about two hours. On the Mond Nickel Company's standards, the coefficient of variation for a single determination was ±1·5%.

To be continued.

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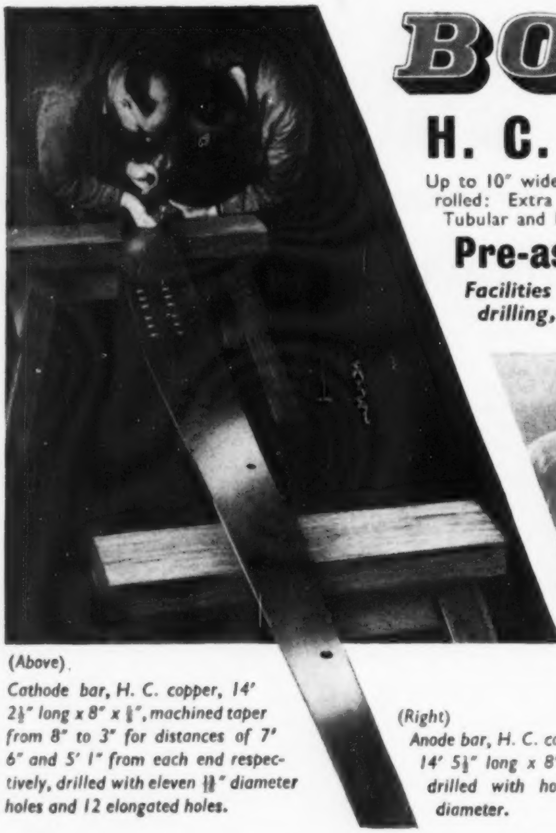

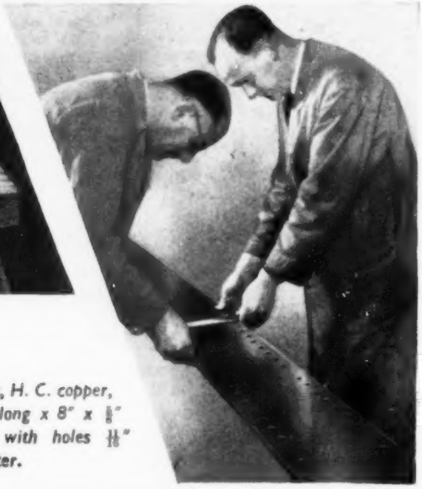

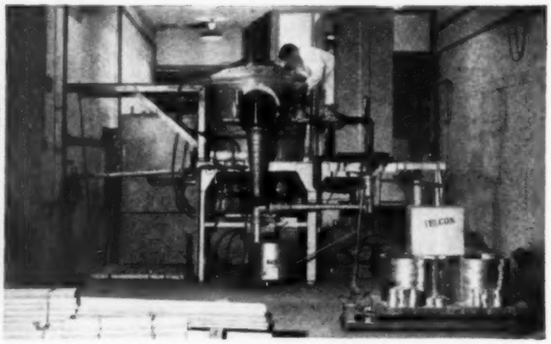

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